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STATISTICAL PROTOCOLS FOR THE HOVIC RCRA PART B PERMIT

Prepared for:

HESS OIL VIRGIN ISLANDS CORP.
St. Croix, U.S. Virgin Islands

Prepared by:

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December 1985

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13 December 1985

Ms. Kathleen Tobin
Environmental Engineer
Region II, U.S. ENVIRONMENTAL PROTECTION AGENCY
26 Federal Plaza
New York, New York 10278

SUBJECT: TRANSMITTAL of STATISTICAL PROTOCOLS for the HOVIC RCRA PART B PERMIT, EPA ID NO. VID 980536080

Dear Ms. Tobin:

On behalf of Hess Oil Virgin Islands Corp. (HOVIC), I am sending you the statistical procedures we have developed to meet the Resource Conservation and Recovery Act (RCRA) Part B permit requirements. The enclosed report entitled, "Statistical Protocols for the HOVIC RCRA Part B Permit" has been developed under 40 CFR 264.97 (h)(ii) for HOVIC by Professor Robert Gibbons of the University of Illinois and our consultant for RCRA matters, Mr. Mike Corn, of the Advent Group as an improved alternative to the Students' t-test as given in 40 CFR 264, Appendix IV. The Students' t-test, as you know, has led to many false positive results across the country on groundwater monitoring wells and unsaturated zone monitoring.

In developing the statistical approach for HOVIC Dr. Robert Gibbons, Professor of Statistics, has suggested a two-tiered approach for statistically analyzing groundwater monitoring data. The first step makes use of the Students' t-test as mandated in the RCRA regulations and modified in order to provide a scientifically and statistically correct procedure. The second step makes use of a non-parametric (that is, data not uniformly distributed around an average) statistical procedure, the Mann-Whitney U test, to test if the modified Students' t-test, a parametric statistical test (data fit a bell-shaped curve), is giving a false positive due to the data being non-parametric. We believe that the statistical approach presented in the attached report meets, and improves upon, the requirements of the 40 CFR 264 regulations.

Hovic seeks the approval and endorsement of these statistical methods by the U. S. Environmental Protection Agency. If you should have any questions or comments concerning the attached report, please contact either Mr. Barry Sams, Environmenal Manager at HOVIC, at (809) 778-4251 or me at (201) 636-3000.

Yours truly,

Theodore Helfgott

T. Helfgott, Ph.D., P.E.
Environmental Affairs Manager

TH:em

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December 10, 1985 2005.24

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Hess Oil Virgin Islands Corp.
Kingshill, P.O. Box 127
St. Croix, U.S. VI 00850

SUBJECT: Report on Statistical Protocols for the HOVIC RCRA Part B Permit

Dear Dr. Helfgott and Mr. Sams:

At your request, I have prepared the enclosed report as referenced above. This report presents a statistical approach to be used at HOVIC in assessing groundwaters and unsaturated zone samples at the Resource Conservation and Recovery Act (RCRA) landfarms at the refinery. In preparing this report, we have included the methodology and approaches suggested by Dr. Robert Gibbons, Professor of Statistics at the University of Illinois at Chicago. Dr. Gibbons has reviewed the statistical approach described in Section 2 of this report and he has also reviewed the actual statistical calculations presented.

The report includes the statistical approach as well as example calculations which test the validity of the approach. As we have discussed, we had some concern with the power of the original approach using the standard Mann-Whitney U test. After review of the original calculations made in September and October of this year, Dr. Gibbons recommended a modification of the Mann- Whitney U test which gives the test the necessary power required to meet the 0.01 and 0.05 levels of significance.

I have also included the recommended constituents for each environmental media (groundwaters, unsaturated zone liquids, and unsaturated zone soil cores) and the media constituent concentration which would require statistical analysis for determination of significant increases over background concentrations or method detection levels.

As you review this report and the methodology, please call me at (615) 377-4775 if you should have any questions or comments.

Sincerely,

Michael R. Corn

Michael R. Corn, P.E.
Consultant

EXECUTIVE SUMMARY

Hess Oil Virgin Islands Corp. (HOVIC) operates a landfarm system at a petroleum refinery located on St. Croix, U.S. Virgin Islands. HOVIC has requested a Resource Conservation and Recovery Act (RCRA) Part B Permit under the requirements of the RCRA regulations 40 CFR 270 and 264. Part of these regulatory requirements include analyzing groundwater and unsaturated zone monitoring data using statistical procedures as described under 40 CFR 264.97. These regulations allow HOVIC to develop an alternative statistical approach in place of the suggested Students' t-test, a test which is prone to false positive results. An alternative statistical approach has been developed under the guidance of a statistician, Dr. Robert Gibbons of the University of Illinois at Chicago.

The approach developed with Dr. Gibbons is a two-tiered approach which first tests the data against a modified Students' t-test for significance as specified in the regulation. Secondly, if significance is indicated then a second test, the non-parametric test -- the Mann-Whitney U test -- is used to check if this significance is the result of the type of test -- the Students' t-test which is a parametric or bell-shaped curve test -- instead of actual constituents originating from the landfarm. In many cases the variance is the result of the limits of the chemical analytic results and background variances especially for measurements at and below sensitive concentrations (levels of detection).

Examples of statistical calculations using this two-tiered approach are included in this report for HOVIC groundwater monitoring data from Landfarms II and III. Conductivities in the downgradient wells at Landfarm II were significantly different under both the modified Students' t-test and the Mann-Whitney U test. This is as expected since the upgradient well at Landfarm II has historically shown about half the conductivity of the downgradient wells. All other indicator parameters were not significantly different when tested under the two-tiered statistical approach presented herein.

Recommended constituents for monitoring and constituent concentration levels adequate for statistical analyses are presented in this report in Table 4. The constituents to be included in the statistical analyses include the Principal Hazardous Constituents previously identified in the HOVIC Waste Analysis Report and the Treatment Demonstration Plan, and several indicator parameters which are specifically characteristics of the oily sludges applied to the landfarms. It is recommended that three indicator parameters -- pH, Conductivity, and Total Organic Halogen (TOX) -- be dropped from future statistical analyses due to natural wide variability at the site (conductivity), differences between in-situ and laboratory measurements (pH), or because of salinity interferences with the laboratory test (TOX). The two-tiered statistical approach can be used for groundwater monitoring data, unsaturated zone liquids (lysimeter samples), and unsaturated zone soil cores for Landfarms II and III.

The approach presented would call for HOVIC to install an additional groundwater monitoring well which can serve jointly as a additional background well for both Landfarms II and III.

The two-tiered statistical approach presented in this report meets the regulatory requirement and augments the use of the Students' t-test. These methods will limit false positives that were prevalent with the original Students' t-test.

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INTRODUCTION

Hess Oil Virgin Islands Corp. (HOVIC) operates two landfarms at a petroleum refinery located on St. Croix, U.S. Virgin Islands. The refinery currently operates the landfarms under interim status authorization -- EPA ID NO. VID 980536080. As part of the RCRA permitting process, HOVIC has submitted a Resource Conservation and Recovery Act (RCRA) Part B Permit application for future operation of these landfarms. Under the RCRA 40 CFR 264 regulations which apply to the Part B Permit -- Paragraph 264.97, a statistical analysis program must be used to determine if statistical differences occur between the water quality parameters being monitored for the upgradient or background wells and downgradient wells (from the land treatment unit). If statistical differences are indicated at the 0.05 level, then the regulations assume that there has been constituent movement from the unit. As part of this application, HOVIC has prepared a statistical approach presented herein to be used for analyzing groundwater quality data and unsaturated zone soil and liquid samples under the RCRA Part B Permit.

BACKGROUND

HOVIC has collected groundwater data since April 1982 from four monitoring wells (one upgradient well and three downgradient wells) at Landfarm II and four monitoring wells at Landfarm III. Specifically, HOVIC has analyzed the groundwater samples for the indicator parameters -- pH, specific conductance at 25 ^{o}C (conductivity), total organic carbon (TOC), and total organic halogen (TOX) -- and two constituents responsible for the waste sludges to be listed under 40 CFR 261 as RCRA wastes, lead and chromium. The data for the indicator parameters have been subjected to the Students' t test as described under 40 CFR 265.93 and Appendix IV of 40 CFR 265. (Note: The lead and chromium data have been used as action level parameters to supplement the statistical tests. That is, if a concentration of 0.035 milligrams per liter or mg/l of lead or chromium were analyzed in the groundwater samples, then this was a true indication of constituent movement from the landfarms, and a groundwater assessment program was to be implemented.) Under the 40 CFR 265 regulations, a statistically significant difference is assumed at the 0.01 level.

The groundwater beneath the HOVIC landfarms has been determined to be brackish to saline. Conductivity measurements indicate that this salinity varies both spatially and temporally across the site. Since the beginning of the HOVIC groundwater monitoring program, the salinity has caused problems (total dissolved solids or TDS interferences) with several of the analyses used in the statistical analyses. The specific analyses which are known to be interfered with by high TDS concentrations in the water samples are total organic carbon (TOC), total organic halogens (TOX as Cl^-), and the metals analyses (specifically lead or Pb and chromium or Cr). Since the inception of the monitoring program, EPA has updated the acceptable procedures which help to account for these laboratory analytical problems caused by the TDS interferences. Along with the EPA procedures, HOVIC and their outside contract laboratories have worked out many of the analytical problems associated with the TDS interferences.

The Students' t test results on the HOVIC groundwater data have indicated statistically significant differences when comparing upgradient and downgradient monitoring wells at a landfarm. These differences are believed to be false positives caused for the most part by the spatial and temporal salinity differences across the site. Lead and chromium concentrations in the groundwater samples have been less than the action level of 0.035 mg/l.

HOVIC has discussed with EPA the problems with the Students' t test and various alternatives to this statistical test which might eliminate the many false positives associated with this method. EPA has recommended that HOVIC develop alternative statistical procedures which might eliminate the false positives while still effectively giving true indications of constituent movement from the landfarms to the underlying groundwater. In these efforts, HOVIC consulted with Dr. Robert Gibbons, Professor of Statistics at the University of Illinois in Chicago, for the development of a technical approach to statistical analyses of the HOVIC groundwater data. The procedures developed and example calculations using the HOVIC data are presented in the following section.

SECTION 2

STATISTICAL PROTOCOLS FOR ANALYSIS OF THE HOVIC GROUNDWATER DATA

SECTION 2

STATISTICAL PROTOCOLS FOR ANALYSIS OF THE HOVIC GROUNDWATER DATA

HOVIC has been using the Students' t test as presented in 40 CFR 265, Appendix IV. The Students' t test is a statistical test for determining if data in one group of test samples, such as the downgradient wells, are related to the control group, in this case the upgradient wells. In this test, some confidence interval must be used and this has been established by regulation at the 0.01 level for the interim status groundwater monitoring and at the 0.05 level for future Part B Permit groundwater monitoring. A significant assumption of the Students' t test is that the data follow a statistically normal distribution (bell-shaped curve).

RECOMMENDED STATISTICAL APPROACH

The HOVIC data, as well as other sites' groundwater monitoring data, would not necessarily be expected to follow a normal distribution. At the advice of Dr. Gibbons, a two-tiered statistical approach was developed as outlined below.

Statistical Analyses of the Indicator Constituents and the Principal Hazardous Constituents

For the indicator parameters and the principal hazardous constituents such as lead, benzene, toluene and 2,4 dimethylphenol expected to be near or below the method detection limits, or are at the refinery background concentrations, the following criteria are to be used.

A threshold concentration has been set which is reflective of method detection limits or known refinery background conditions. If the constituent concentration in a sample from the media being monitored -- groundwater, unsaturated zone liquids, or unsaturated zone soil cores -- is higher than these established threshold concentrations, then the data are assumed candidates for potential statistical differences. The data will then be subjected to statistical analyses described in Steps 1 and 2 which follow. If the data are below these threshold limits, then the data are assumed to be not statistically different from background conditions. As an example, a threshold concentration for benzene of 50 micrograms per liter (μg/l or ppb in any groundwater sample or lysimeter sample is set as the limit at which statistical analyses will be implemented. That is, if benzene is detected at 50 ppb in a well (either upgradient or downgradient), then that parameter (benzene) is subjected to the Mann-Whitney U test. Since this test ranks data (that is, puts the data in ascending order), less than detection limits results can be factored into the statistical test without having to define what the less than number actually is.

The method limits of detection for soil samples will be dependent on the specific analytical test selected. A set point for statistical analyses for the soil samples has beeen established based on the specific method limits of detection achievable. The results of the Mann- Whitney U test would be used to determine if there has been a significant increase in the particular parameter tested; that is, a significant increase from upgradient to downgradient.

Step 1. Analyze the data using the Students' t test. The approach is to obtain quarterly data from the background wells. At least 8 to 16 independent groundwater quality data from the background well(s) are compared with the most recently collected groundwater data for each downgradient well at each landfarm. The four replicate measurements of one groundwater sample (for a specific parameter such as conductivity) obtained during any one sampling round are averaged to yield one data point. That is, for each sample period only one data point (an average of the four replicate measurements) are used per individual groundwater monitoring well sampled. As an example, in order to obtain twelve independent background data points, either the last consecutive twelve sample rounds of data are used or the last six consecutive sample rounds of data from two background wells at a landfarm will be used. These twelve values are converted to natural logarithms and compared at the 0.05 confidence level using the Students' t test with the natural logarithm of the value for the downgradient well (natural logarithm of the average of the four replicate data results). The natural logarithms are used so that all constituents are comparable (because pH is a logarithmic function). If there are significant differences, then the data are subjected to a non-parametric test (that is , Mann-Whitney U test as described in Attachment 1). A nonparametric distribution does not follow a normal distribution (bell-shaped curve). If results are inconsistent then one assumes that the difference is due to distributional misspecification (that is, these data are not distributed normally -- statistically in a classsical bell-shaped curve -- as is assumed by the Students' t test statistic, but not by the Mann-Whitney U statistical test). Concordance between the results of these two tests suggest that the empirical distribution of these data are not affecting the test results.

Step 2. Analyze the data using a nonparametric statistical test, the Mann-Whitney U test. If there is a statistically significant increase (or pH decrease) in a parameter for a groundwater monitoring well based on the Students' t test results, then the non-parametric statistical test, the Mann-Whitney U test, is to be run on the data. The log means of the eight most recent data results from the background groundwater monitoring well are compared with the means of the data results from three downgradient groundwater monitoring wells. The Mann-Whitney U test procedure to be used is described in Attachment 1. If a non-significant result is obtained from the Mann-Whitney U test statistic, then this suggests that these data did not follow a normal distribution. Therefore, the use of the Students' t test is inappropriate for the analysis of these data. If a positive finding or significant increase also results from the Mann-Whitney U test, then there has most likely been a significant increase in that parameter. Therefore, a positive finding using both the Students' t test (a parametric test or test of normally distributed data) and the Mann-Whitney U test (a nonparametric test) is an indication that a significant increase in that parameter has occurred in the groundwater monitoring well based on comparisons with the upgradient well(s).

EXAMPLE CALCULATIONS

The HOVIC groundwater monitoring data for Landfarms II and III are presented in Attachment 2. These data were subjected to the two-tiered statistical approach given above. Examples of the modified Students' t test results and for the Mann-Whitney U test results for conductivity are given in Tables 1 and 2. The conductivities in the downgradient wells at Landfarm III were not significantly different than the upgradient wells. The conductivity for the downgradient wells at Landfarm II were significantly different than the upgradient well in both tests. This is as expected since the upgradient well at Landfarm II is of much lower conductivity than the downgradient wells as is depicted in Figure 1. Test results for all four indicator parameters are given in Table 3 and the calculations are presented in Attachment 3.

It is noted that statistical differences have been indicated for pH since the inception of the HOVIC groundwater monitoring program. It has been well documented that <u>in-situ</u> measurements in the groundwater monitoring well of pH versus groundwater brought to the surface or to the laboratory for measurements of pH are almost always different. For the most part, this phenomenon is caused by dissolved carbon dioxide, which is in the form of naturally occurring bicarbonates or carbonates in groundwater, escaping from the samples as they are exposed to the atmosphere. The typical result of this is that <u>in-situ</u> measurements for pH are for the most part lower (more acidic) than pH measurements on the same water sample once it is brought to the surface, that is, CO_2 is evolved depleting the natural weak carbonic acid solution in the groundwater. There is an equilibrium solution (groundwater) between CO_2, carbonic acid, bicarbonates and carbonates -- all naturally present. This was documented for the HOVIC wells during groundwater sample collections which were conducted in October 1985. A Hydrolab 8000 water quality instrument was used to measure <u>in-situ</u> water temperature, pH, dissolved oxygen (DO), and oxidation-reduction potential (ORP) in the monitoring wells at both Landfarm II and Landfarm III. Groundwater samples were collected and taken to the HOVIC onsite laboratory for pH measurement. The data are presented in Attachment 4. The pH in the wells was typically between 6 to 7 and in the laboratory between 7 which is expected for saline waters (seawater has a pH of around 8). The change in pH from in-the-well to the surface is due to the carbon dioxide loss from the water samples once they reach the surface. It is recommended that pH be dropped as a parameter for statistical analysis under the RCRA Part B Permit because of these naturally occurring chemical phonomena. Additionally, conductivity is naturally high beneath the HOVIC site as well as being both spatially and temporally different. It is recommended that conductivity not be included in future statistical analyses under the RCRA Part B

Permit. A third parameter, TOX, should also be dropped from the indicator list under the Part B Permit. TOX is measured as Cl^-, and in the groundwaters at HOVIC the TOX measurements are influenced by the high salinity.

FUTURE MONITORING AND STATISTICAL ANALYSES

In order to achieve the necessary number of samples required for statistical analyses, either quarterly groundwater samples should be required or an additional background well should be required for each landfarm. It is recommended that an additional background well be placed between Landfarm II and Landfarm III as presented in Figure 2. This well would be used as a second background well for both Landfarms II and III. Thus the wells could still be sampled semiannually and a total of eight background samples could be obtained within a two-year period which would give the statistical tests the necessary power for determining significance at the 0.05 level.

The parameters to be subjected to the statistical analyses are given in Table 4. Groundwater monitoring is recommended to be done on a semiannual basis if two background wells are available at the landfarms. Otherwise, quarterly groundwater monitoring should be required.

TABLE 1. MODIFIED STUDENTS' t TEST FOR CONDUCTIVITY AT LANDFARMS II

LANDFARM	MONITORING WELL #	MONITORING WELL # LOCATION	SAMPLING DATE	CONDUCTI (umhos/
II	NSF-1	upgradient	27-Sep-84	1
	NSF-1	upgradient	06-Mar-84	3
	NSF-1	upgradient	12-Apr-84	2
	NSF-1	upgradient	03-Jun-84	2
	NSF-1	upgradient	20-Aug-84	2
	NSF-1	upgradient	28-Nov-84	2
	NSF-1	upgradient	20-Mar-85	2
	NSF-1	upgradient	01-Jul-85	2
	NSF-2	downgradient	01-Jul-85	4
	NSF-3	downgradient	01-Jul-85	4
	NSF-4	downgradient	01-Jul-85	4
III	SSF-1	upgradient	27-Sep-84	[illegible]
	SSF-1	upgradient	06-Mar-84	[illegible]
	SSF-1	upgradient	12-Apr-84	[illegible]
	SSF-1	upgradient	03-Jun-84	[illegible]
	SSF-1	upgradient	20-Aug-84	[illegible]
	SSF-1	upgradient	28-Nov-84	[illegible]
	SSF-1	upgradient	20-Mar-85	
	SSF-1	upgradient	01-Jul-85	[illegible]
	SSF-2	downgradient	01-Jul-85	
	SSF-3	downgradient	01-Jul-85	
	SSF-4	downgradient	01-Jul-85	

NOTE: A - THERE HAS NOT BEEN A SIGNIFICANT CHANGE IN THIS PARAMETER

B - MOST LIKELY THERE HAS BEEN A SIGNIFICANT INCREASE (OR pH

I

ln CONDUCTIVITY	$\overline{x}$-bg	s^2-bg	$\sqrt{s^2\text{-bg}/n}$	$\overline{x}$-dg	t*	tc	STANDING
9.8653							
10.3090							
10.2921							
10.3006							
10.1562							
9.9874							
9.9758							
10.0541							
	10.1175	0.0295	0.0608				
10.6748				10.6748	9.1686	1.8950	B
10.6573				10.6573	8.8808	1.8950	B
10.8047				10.8047	11.3063	1.8950	B
10.1659							
10.7032							
10.6919							
10.8297							
10.8198							
10.7088							
10.7144							
10.7255							
	10.6699	0.0443	0.0744				
10.6454				10.6454	-0.3290	1.8950	A
10.4773				10.4773	-2.5878	1.8950	A
10.6690				10.6690	-0.0128	1.8950	A

ASE) IN THIS PARAMETER

TABLE 2. MANN-WHITNEY U TEST FOR CONDUCTIVITY AT LANDFARMS II AND I

LANDFARM	MONITORING WELL #	MONITORING WELL # LOCATION	SAMPLING DATE	CONDUCT (umhos
II	NSF-1	upgradient	27-Sep-84	
	NSF-1	upgradient	20-Mar-85	
	NSF-1	upgradient	28-Nov-84	
	NSF-1	upgradient	01-Jul-85	
	NSF-1	upgradient	20-Aug-84	
	NSF-1	upgradient	12-Apr-84	
	NSF-1	upgradient	03-Jun-84	
	NSF-1	upgradient	06-Mar-84	
	NSF-3	downgradient	01-Jul-85	
	NSF-2	downgradient	01-Jul-85	
	NSF-4	downgradient	01-Jul-85	
III	SSF-1	upgradient	27-Sep-84	
	SSF-3	downgradient	01-Jul-85	
	SSF-2	downgradient	01-Jul-85	
	SSF-4	downgradient	01-Jul-85	
	SSF-1	upgradient	12-Apr-84	
	SSF-1	upgradient	06-Mar-84	
	SSF-1	upgradient	28-Nov-84	
	SSF-1	upgradient	20-Mar-85	
	SSF-1	upgradient	01-Jul-85	
	SSF-1	upgradient	20-Aug-84	
	SSF-1	upgradient	03-Jun-84	

NOTE: A - THERE HAS NOT BEEN A SIGNIFICANT CHANGE IN THIS PARAMETER

B - MOST LIKELY THERE HAS BEEN A SIGNIFICANT INCREASE) IN THI

SEE ATTACHMENT 1, TABLE J FOR N2 FOR PROBABILITIES (P-1 OR P-

ln CONDUCTIVITY	U-1	U-2 (pH only)	P-1	P-2 (pH only)	STANDING	CONFIDENCE INTERVAL
9.8653	0					
9.9758	0					
9.9874	0					
10.0541	0					
10.1562	0					
10.2921	0					
10.3006	0					
10.3090	0					
10.6573						
10.6748						
10.8047						
	0		0.006		B	0.05
					B	0.01
10.1659	0					
10.4773						
10.6454						
10.6690						
10.6919	3					
10.7032	3					
10.7088	3					
10.7144	3					
10.7255	3					
10.8198	3					
10.8297	3					
	12		0.539		A	0.05
					A	0.01

METER

RSUS U

TABLE 3. SUMMARY OF HOVIC STATISTICAL ANALYSES RESULTS

LANDFARM	MONITORING WELL #	INDICATOR PARAMETER: pH STATISTICAL TEST: Behrens-Fisher t-test	pH modified t-test	pH Mann-Whitney U test	conductivity Behrens-Fisher t-test
II	NSF-1	A			A
	NSF-2	B	B	A	B
	NSF-3	B	A	A	B
	NSF-4	B	A	A	B
	SSF-1	B			B
	SSF-2	B	A	A	B
	SSF-3	B	A	A	B
	SSF-4	B	A	A	B

NOTES: A - THERE HAS NOT BEEN A SIGNIFICANT CHANGE IN THIS PARAMETER

B - MOST LIKELY THERE HAS BEEN A SIGNIFICANT INCREASE IN THIS PARAMETER

CONFIDENCE INTERVALS :

BEHRENS-FISHER t-TEST - 0.01
MODIFIED t-TEST - 0.05
MANN-WHITNEY U TEST - 0.05

uctivity	conductivity	TOC	TOC	TOC	TOX	TOX	TOX
dified -test	Mann-Whitney U test	Behrens-Fisher t-test	modified t-test	Mann-Whitney U test	Behrens-Fisher t-test	modified t-test	Mann-Whitney U test
		A			A		
B	B	A	B	A	A	A	A
B	B	A	A	A	A	A	A
B	B	A	A	A	A	A	A
		A			A		
A	A	A	A	A	A	A	A
A	A	A	A	A	A	A	A
A	A	A	A	A	A	A	A

TABLE 4. MEDIA/CONSTITUENT STATISTICAL ANALYSES

CONSTITUENT MONITORED	MEDIA	
	TREATMENT ZONE	UNSATURAT
	SOIL CORE COMPOSITES	SC
	SOIL SAMPLES (0 - 5 ft)	SOI (5
PRINCIPAL HAZARDOUS CONSTITUENTS		
METALS		
barium		
chromium		
lead		
vanadium		
VOLATILE COMPOUNDS		
benzene		
toluene		
ACID COMPOUNDS		
2,4-dimethylphenol		
BASE/NEUTRAL COMPOUNDS		
benzo(a)pyrene		
naphthalene		
INDICATOR PARAMETERS		
pH		
conductivity		
total nitrogen		
oil and grease		
phenols		
total organic carbon (TOC)		

			CONCENTRATION FOR STATISTICAL ANALYSES		
IE		GROUNDWATER	UNSATURATED ZONE		GROUNDWATER
ES	LYSIMETERS	MONITORING WELLS	SOIL CORES	LYSIMETERS	MONITORING WELLS
LES t)	LIQUIDS	WATER	SOIL SAMPLES (5 - 6 ft) (mg/kg)	LIQUIDS (mg/l)	WATER (mg/l)
			70		
			70		
			70		
			70		
	x	x		0.050	0.050
	x	x		0.050	0.050
	x	x		0.050	0.050
			50		
			50		
	x	x	3900	10	10
	x	x	10	1	1
	x	x	50	20	20

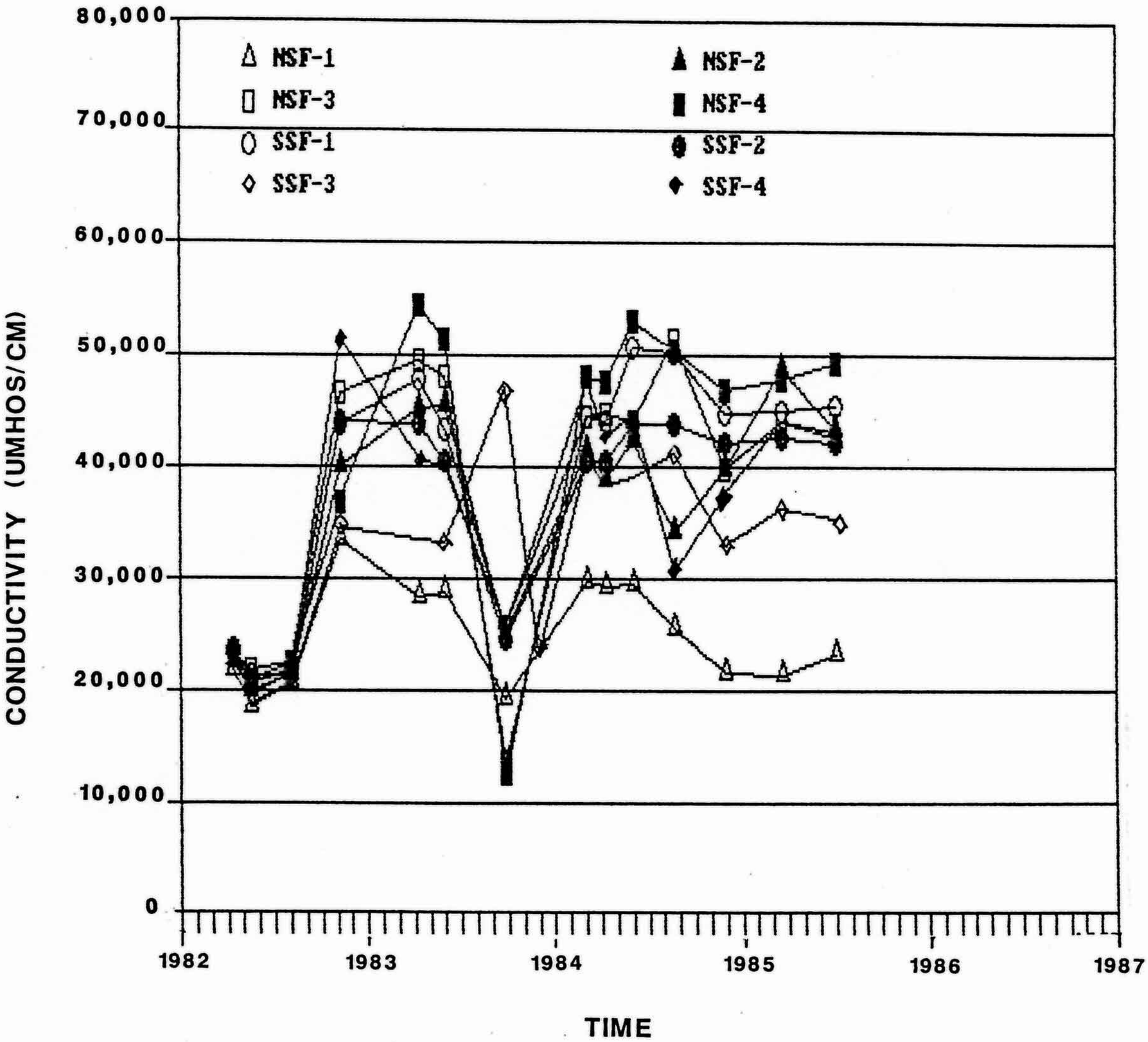

FIGURE 1

CONDUCTIVITY MEASUREMENTS FROM RCRA WELLS AT LANDFARMS II AND III

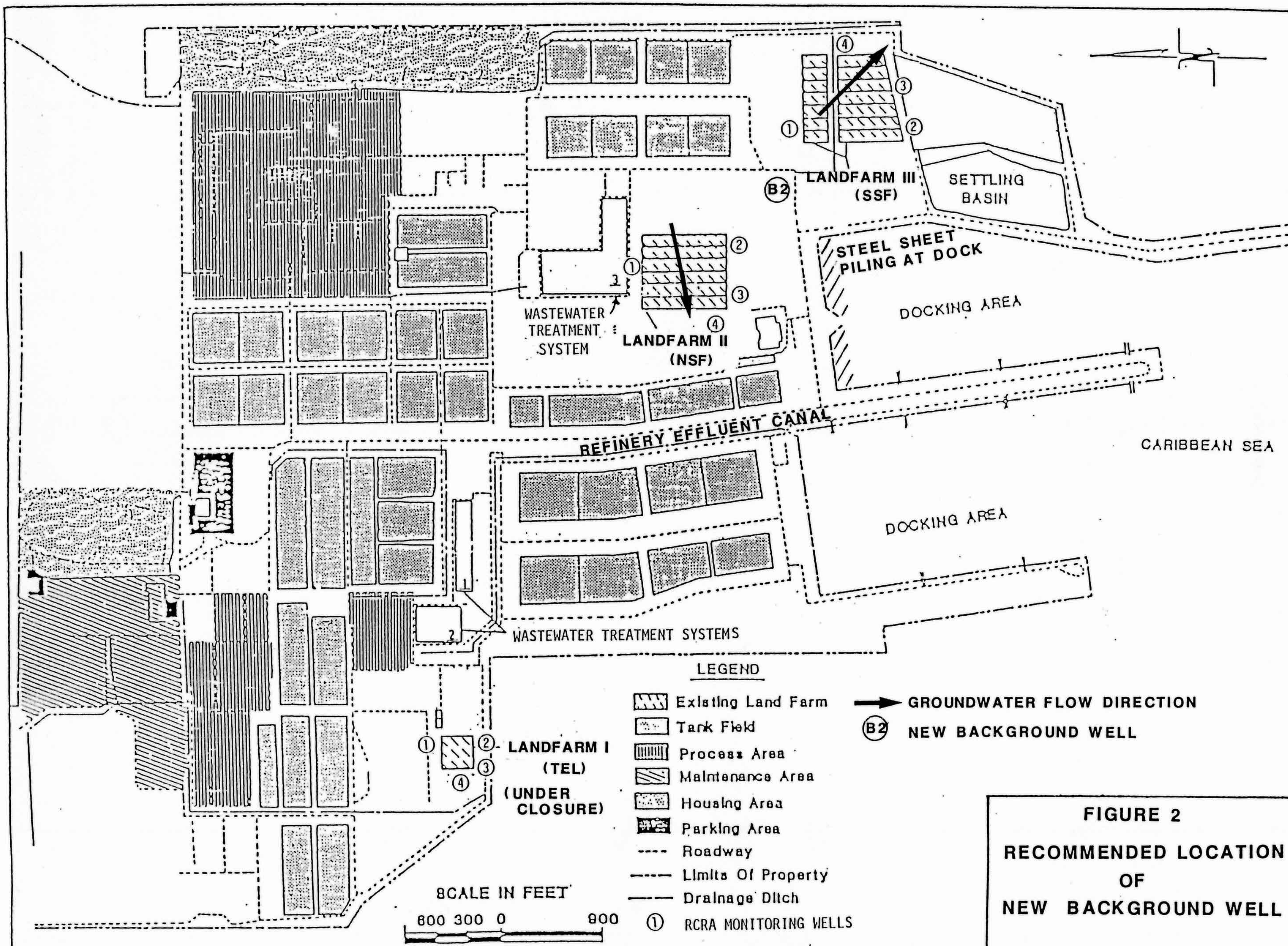

FIGURE 2
RECOMMENDED LOCATION OF NEW BACKGROUND WELL

ATTACHMENT 1

MANN-WHITNEY U TEST PROCEDURES

(From Siegel. 1956.
Nonparametric Statistics for the Behavioral Sciences.
McGraw-Hill, NY.)

References

Discussions of the median test are contained in Brown and Mood (1951), Mood (1950, pp. 394–395), and Moses (1952a).

THE MANN-WHITNEY U TEST

Function

When at least ordinal measurement has been achieved, the Mann-Whitney U test may be used to test whether two independent groups have been drawn from the same population. This is one of the most powerful of the nonparametric tests, and it is a most useful alternative to the parametric t test when the researcher wishes to avoid the t test's assumptions, or when the measurement in the research is weaker than interval scaling.

Suppose we have samples from two populations, population A and population B. The null hypothesis is that A and B have the same distribution. The alternative hypothesis, H_1, against which we test H_0, is that A is stochastically larger than B, a directional hypothesis. We may accept H_1 if the probability that a score from A is larger than a score from B is greater than one-half. That is, if a is one observation from population A, and b is one observation from population B, then H_1 is that $p(a > b) > \frac{1}{2}$. If the evidence supports H_1, this implies that the "bulk" of population A is higher than the bulk of population B.

Of course, we might predict instead that B is stochastically larger than A. Then H_1 would be that $p(a > b) < \frac{1}{2}$. Confirmation of this assertion would imply that the bulk of B is higher than the bulk of A.

For a two-tailed test, i.e., for a prediction of differences which does not state direction, H_1 would be that $p(a > b) \neq \frac{1}{2}$.

Method

Let n_1 = the number of cases in the smaller of two independent groups, and n_2 = the number of cases in the larger. To apply the U test, we first combine the observations or scores from both groups, and rank these in order of increasing size. In this ranking, algebraic size is considered, i.e., the lowest ranks are assigned to the largest negative numbers, if any.

Now focus on one of the groups, say the group with n_1 cases. The value of U (the statistic used in this test) is given by the number of times that a score in the group with n_2 cases precedes a score in the group with n_1 cases in the ranking.

For example, suppose we had an experimental group of 3 cases and a control group of 4 cases. Here $n_1 = 3$ and $n_2 = 4$. Suppose these were

the scores:

n_1	E scores	9	11	15		3 downgradient
n_2	C scores	6	8	10	13	8 upgradient

To find U, we first rank these scores in order of increasing size, being careful to retain each score's identity as either an E or C score:

6	8	9	10	11	13	15
C	C	E	C	E	C	E

Now consider the control group, and count the number of E scores that precede each score in the control group. For the C score of 6, no E score precedes. This is also true for the C score of 8. For the next C score (10), one E score precedes. And for the final C score (13), two E scores precede. Thus $U = 0 + 0 + 1 + 2 = 3$. The number of times that an E score precedes a C score is $3 = U$.

The sampling distribution of U under H_0 is known, and with this knowledge we can determine the probability associated with the occurrence under H_0 of any U as extreme as an observed value of U.

* **Very small samples.** When neither n_1 nor n_2 is larger than 8, Table J of the Appendix may be used to determine the exact probability associated with the occurrence under H_0 of any U as extreme as an observed value of U. The reader will observe that Table J is made up of six separate subtables, one for each value of n_2, from $n_2 = 3$ to $n_2 = 8$. To determine the probability under H_0 associated with his data, the researcher need know only n_1 (the size of the smaller group), n_2, and U. With this information he may read the value of p from the subtable appropriate to his value of n_2.

In our example, $n_1 = 3$, $n_2 = 4$, and $U = 3$. The subtable for $n_2 = 4$ in Table J shows that $U \leq 3$ has probability of occurrence under H_0 of $p = .200$.

The probabilities given in Table J are one-tailed. For a two-tailed test, the value of p given in the table should be doubled.

Now it may happen that the observed value of U is so large that it does not appear in the subtable for the observed value of n_2. Such a value arises when the researcher focuses on the "wrong" group in determining U. We shall call such a too-large value U'. For example, suppose that in the above case we had counted the number of C scores preceding each E score rather than counting the number of E scores preceding each C score. We would have found that $U = 2 + 3 + 4 = 9$. The subtable for $n_2 = 4$ does not go up to $U = 9$. We therefore denote our observed value as $U' = 9$. We can transform any U' to U by

$$U = n_1 n_2 - U' \tag{6.6*}$$

* $p(U > U') = p(U < n_1 n_2 - U')$.

In our example, by this transformation $U = (3)(4) - 9 = 3$. Of course this is the U we found directly when we counted the number of E scores preceding each C score.

Example for Very Small Samples

Solomon and Coles[1] studied whether rats would generalize learned imitation when placed under a new drive and in a new situation. Five rats were trained to imitate leader rats in a T maze. They were trained to follow the leaders when hungry, in order to attain a food incentive. Then the 5 rats were each transferred to a shock-avoidance situation, where imitation of leader rats would have enabled them to avoid electric shock. Their behavior in the shock-avoidance situation was compared to that of 4 controls who had had no previous training to follow leaders. The hypothesis was that the 5 rats who had already been trained to imitate would transfer this training to the new situation, and thus would reach the learning criterion in the shock-avoidance situation sooner than would the 4 control rats. The comparison is in terms of how many trials each rat took to reach a criterion of 10 correct responses in 10 trials.

i. *Null Hypothesis.* H_0: the number of trials to the criterion in the shock-avoidance situation is the same for rats previously trained to follow a leader to a food incentive as for rats not previously trained. H_1: rats previously trained to follow a leader to a food incentive will reach the criterion in the shock-avoidance situation in fewer trials than will rats not previously trained.

ii. *Statistical Test.* The Mann-Whitney U test is chosen because this study employs two independent samples, uses small samples, and uses measurement (number of trials to criterion as an index to speed of learning) which is probably at most in an ordinal scale.

iii. *Significance Level.* Let $\alpha = .05$. $n_1 = 4$ control rats, and $n_2 = 5$ experimental rats.

iv. *Sampling Distribution.* The probabilities associated with the occurrence under H_0 of values as small as an observed U for $n_1, n_2 \leq 8$ are given in Table J.

v. *Rejection Region.* Since H_1 states the direction of the predicted difference, the region of rejection is one-tailed. It consists of all values of U which are so small that the probability associated with their occurrence under H_0 is equal to or less than $\alpha = .05$.

vi. *Decision.* The number of trials to criterion required by the E

[1] Solomon, R. L., and Coles, M. R. 1954. A case of failure of generalization of imitation across drives and across situations. *J. Abnorm. Soc. Psychol.*, 49, 7–13.

and C rats were:

E rats	78	64	75	45	82
C rats	110	70	53	51	

We arrange these scores in the order of their size, retaining the identity of each:

45	51	53	64	70	75	78	82	110
E	C	C	E	C	E	E	E	C

We obtain U by counting the number of E scores preceding each C score: $U = 1 + 1 + 2 + 5 = 9$.

In Table J, we locate the subtable for $n_2 = 5$. We see that $U \leq 9$ when $n_1 = 4$ has a probability of occurrence under H_0 of $p = .452$. Our decision is that the data do not give evidence which justify rejecting H_0 at the previously set level of significance. The conclusion is that these data do not support the hypothesis that previous training to imitate will generalize across situations and across drives.[1]

n_2 between 9 and 20. If n_2 (the size of the larger of the two independent samples) is larger than 8, Table J may not be used. When n_2 is between 9 and 20, significance tests may be made with the Mann-Whitney test by using Table K of the Appendix which gives critical values of U for significance levels .001, .01, .025, and .05 for a one-tailed test. For a two-tailed test, the significance levels given are .002, .02, .05, and .10.

Notice that this set of tables gives critical values of U, and does not give exact probabilities (as does Table J). That is, if an observed U for a particular $n_1 \leq 20$ and n_2 between 9 and 20 is equal to or less than that value given in the table, H_0 may be rejected at the level of significance indicated at the head of that table.

For example, if $n_1 = 6$ and $n_2 = 13$, a U of 12 enables us to reject H_0 at $\alpha = .01$ for a one-tailed test, and to reject H_0 at $\alpha = .02$ for a two-tailed test.

Computing the value of U. For fairly large values of n_1 and n_2, the counting method of determining the value of U may be rather tedious. An alternative method, which gives identical results, is to assign the

[1] Solomon and Coles report the same conclusion. The statistical test which they

rank of 1 to the lowest score in the combined $(n_1 + n_2)$ group of scores, assign rank 2 to the next lowest score, etc. Then

$$U = n_1 n_2 + \frac{n_1(n_1 + 1)}{2} - R_1 \tag{6.7a}$$

or, equivalently,

$$U = n_1 n_2 + \frac{n_2(n_2 + 1)}{2} - R_2 \tag{6.7b}$$

where R_1 = sum of the ranks assigned to group whose sample size is n_1
R_2 = sum of the ranks assigned to group whose sample size is n_2

For example, we might have used this method in finding the value of U for the data given in the example for small samples above. The E and C scores for that example are given again in Table 6.13, with their ranks.

TABLE 6.13. TRIALS TO CRITERION OF E AND C RATS

E Score	Rank	C Score	Rank
78	7	110	9
64	4	70	5
75	6	53	3
45	1	51	2
82	8		
	$R_2 = 26$		$R_1 = 19$

For those data, $R_1 = 19$ and $R_2 = 26$, and it will be remembered that $n_1 = 4$ and $n_2 = 5$. By applying formula (6.7b), we have

$$U = (4)(5) + \frac{5(5 + 1)}{2} - 26$$
$$= 9$$

$U = 9$ is of course exactly the value we found earlier by counting.

Formulas (6.7a) and (6.7b) yield different U's. It is the smaller of these that we want. The larger value is U'. The investigator should check whether he has found U' rather than U by applying the transformation

$$U = n_1 n_2 - U' \tag{6.6}$$

The smaller of the two values, U, is the one whose sampling distribution is the basis for Table K. Although this value can be found by computing both formulas (6.7a) and (6.7b) and choosing the smaller of the two results, a simpler method is to use only one of those formulas and then find the other value by formula (6.6).

Large samples (n_2 larger than 20). Neither Table J nor Table K is usable when $n_2 > 20$. However, it has been shown (Mann and Whitney, 1947) that as n_1, n_2 increase in size, the sampling distribution of U rapidly approaches the normal distribution, with

$$\text{Mean} = \mu_U = \frac{n_1 n_2}{2}$$

and $$\text{Standard deviation} = \sigma_U = \sqrt{\frac{(n_1)(n_2)(n_1 + n_2 + 1)}{12}}$$

That is, when $n_2 > 20$ we may determine the significance of an observed value of U by

$$z = \frac{U - \mu_U}{\sigma_U} = \frac{U - \frac{n_1 n_2}{2}}{\sqrt{\frac{(n_1)(n_2)(n_1 + n_2 + 1)}{12}}} \tag{6.8}$$

which is practically normally distributed with zero mean and unit variance. That is, the probability associated with the occurrence under H_0 of values as extreme as an observed z may be determined by reference to Table A of the Appendix.

When the normal approximation to the sampling distribution of U is used in a test of H_0, it does not matter whether formula (6.7a) or (6.7b) is used in the computation of U, for the absolute value of z yielded by formula (6.8) will be the same if either is used. The sign of the z depends on whether U or U' was used, but the value does not.

Example for Large Samples

For our example, we will reexamine the Whiting and Child data which we have already analyzed by the median test (on pages 112 to 115).

i. *Null Hypothesis.* H_0: oral socialization anxiety is equally severe in both societies with oral explanations of illness present and societies with oral explanations absent. H_1: societies with oral explanations of illness present are (stochastically) higher in oral socialization anxiety than societies which do not have oral explanations of illness.

ii. *Statistical Test.* The two groups of societies constitute two independent groups, and the measure of oral socialization anxiety (rating scale) constitutes an ordinal measure at best. For these reasons the Mann-Whitney U test is appropriate for analyzing these data.

iii. *Significance Level.* Let $\alpha = .01$. $n_1 = 16$ = the number of societies with oral explanations absent; $n_2 = 23$ = the number of societies with oral explanations present.

iv. *Sampling Distribution.* For $n_2 > 20$, formula (6.8) yields values of z. The probability associated with the occurrence under H_0 of values as extreme as an observed z may be determined by reference to Table A.

v. *Rejection Region.* Since H_1 predicts the direction of the difference, the region of rejection is one-tailed. It consists of all values of z (from data in which the difference is in the predicted direction) which are so extreme that their associated probability under H_0 is equal to or less than $\alpha = .01$.

vi. *Decision.* The ratings assigned to each of the 39 societies are shown in Table 6.14, together with the rank of each in the combined

TABLE 6.14. ORAL SOCIALIZATION ANXIETY AND ORAL EXPLANATIONS OF ILLNESS

Societies with oral explanations absent	Rating on oral socialization anxiety	Rank	Societies with oral explanations present	Rating on oral socialization anxiety	Rank
Lapp	13	29.5	Marquesans	17	39
Chamorro	12	24.5	Dobuans	16	38
Samoans	12	24.5	Baiga	15	36
Arapesh	10	16	Kwoma	15	36
Balinese	10	16	Thonga	15	36
Hopi	10	16	Alorese	14	33
Tanala	10	16	Chagga	14	33
Paiute	9	12	Navaho	14	33
Chenchu	8	9.5	Dahomeans	13	29.5
Teton	8	9.5	Lesu	13	29.5
Flathead	7	5	Masai	13	29.5
Papago	7	5	Lepcha	12	24.5
Venda	7	5	Maori	12	24.5
Warrau	7	5	Pukapukans	12	24.5
Wogeo	7	5	Trobrianders	12	24.5
Ontong-Javanese	6	1.5	Kwakiutl	11	20.5
			Manus	11	20.5
			Chiricahua	10	16
		$R_1 = 200.0$	Comanche	10	16
			Siriono	10	16
			Bena	8	9.5
			Slave	8	9.5
			Kurtatchi	6	1.5
					$R_2 = 580.0$

group. Notice that tied ratings are assigned the average of the tied ranks. For these data, $R_1 = 200.0$ and $R_2 = 580.0$. The value of U may be found by substituting the observed values in formula (6.7a):

$$U = n_1n_2 + \frac{n_1(n_1+1)}{2} - R_1 \tag{6.7a}$$

$$= (16)(23) + \frac{16(16+1)}{2} - 200$$

$$= 304$$

Knowing that $U = 304$, we may find the value of z by substituting in formula (6.8):

$$z = \frac{U - \frac{n_1n_2}{2}}{\sqrt{\frac{(n_1)(n_2)(n_1+n_2+1)}{12}}} \tag{6.8}$$

$$= \frac{304 - \frac{(16)(23)}{2}}{\sqrt{\frac{(16)(23)(16+23+1)}{12}}}$$

$$= 3.43$$

Reference to Table A reveals that $z \geq 3.43$ has a one-tailed probability under H_0 of $p < .0003$. Since this p is smaller than $\alpha = .01$, our decision is to reject H_0 in favor of H_1.* We conclude that societies with oral explanations of illness present are (stochastically) higher in oral socialization anxiety than societies with oral explanations absent.

It is important to notice that for these data the Mann-Whitney U test exhibits greater power to reject H_0 than the median test. Testing a similar hypothesis about these data, the median test yielded a value which permitted rejection of H_0 at the $p < .005$ level (one-tailed test), whereas the Mann-Whitney test yielded a value which permitted rejection of H_0 at the $p < .0003$ level (one-tailed test). The fact that the Mann-Whitney test is more powerful than the median test is not surprising, inasmuch as it considers the rank value of each observation rather than simply its location with respect to the combined median, and thus uses more of the information in the data.

Ties. The Mann-Whitney test assumes that the scores represent a distribution which has underlying continuity. With very precise measurement of a variable which has underlying continuity, the probability of a tie is zero. However, with the relatively crude measures which we typically employ in behavioral scientific research, ties may well occur.

* As we have already noted, Whiting and Child reached the same decision on the basis of the parametric t test. They found that $t = 4.05$, $p < .0005$.

We assume that the two observations which obtain tied scores are really different, but that this difference is simply too refined or minute for detection by our crude measures.

When tied scores occur, we give each of the tied observations the average of the ranks they would have had if no ties had occurred.

If the ties occur between two or more observations in the same group, the value of U is not affected. But if ties occur between two or more observations involving both groups, the value of U is affected. Although the effect is usually negligible, a correction for ties is available for use with the normal curve approximation which we employ for large samples.

The effect of tied ranks is to change the variability of the set of ranks. Thus the correction for ties must be applied to the standard deviation of the sampling distribution of U. Corrected for ties, the standard deviation becomes

$$\sigma_U = \sqrt{\left(\frac{n_1 n_2}{N(N-1)}\right)\left(\frac{N^3 - N}{12} - \Sigma T\right)}$$

where $N = n_1 + n_2$

$T = \frac{t^3 - t}{12}$ (where t is the number of observations tied for a given rank)

ΣT is found by summing the T's over all groups of tied observations

With the correction for ties, we find z by

$$z = \frac{U - \frac{n_1 n_2}{2}}{\sqrt{\left(\frac{n_1 n_2}{N(N-1)}\right)\left(\frac{N^3 - N}{12} - \Sigma T\right)}} \tag{6.9}$$

It may be seen that if there are no ties, the above expression reduces directly to that given originally for z [formula (6.8)].

The use of the correction for ties may be illustrated by applying that correction to the data in Table 6.14. For those data,

$$n_1 + n_2 = 16 + 23 = 39 = N$$

We observe these tied groups:

2 scores of 6
5 scores of 7
4 scores of 8
7 scores of 10
2 scores of 11
6 scores of 12
4 scores of 13
3 scores of 14
3 scores of 15

Thus we have t's of 2, 5, 4, 7, 2, 6, 4, 3, and 3. To find ΣT, we sum the values of $\frac{t^3 - t}{12}$ for each of these tied groups:

$$\begin{aligned}\Sigma T &= \frac{2^3 - 2}{12} + \frac{5^3 - 5}{12} + \frac{4^3 - 4}{12} + \frac{7^3 - 7}{12} + \frac{2^3 - 2}{12} + \frac{6^3 - 6}{12} \\ &\qquad + \frac{4^3 - 4}{12} + \frac{3^3 - 3}{12} + \frac{3^3 - 3}{12} \\ &= .5 + 10.0 + 5.0 + 28.0 + .5 + 17.5 + 5.0 + 2.0 + 2.0 \\ &= 70.5\end{aligned}$$

Thus for the data in Table 6.14, $n_1 = 16$, $n_2 = 23$, $N = 39$, $U = 304$, and $\Sigma T = 70.5$. Substituting these values in formula (6.9), we have

$$z = \frac{U - \frac{n_1 n_2}{2}}{\sqrt{\left(\frac{n_1 n_2}{N(N-1)}\right)\left(\frac{N^3 - N}{12} - \Sigma T\right)}} \tag{6.9}$$

$$= \frac{304 - \frac{(16)(23)}{2}}{\sqrt{\left(\frac{(16)(23)}{39(39-1)}\right)\left(\frac{(39)^3 - 39}{12} - 70.5\right)}}$$

$$= 3.45$$

The value of z when corrected for ties is a little larger than that found earlier when the correction was not incorporated. The difference between $z \geq 3.43$ and $z \geq 3.45$, however, is negligible in so far as the probability given by Table A is concerned. Both z's are read as having an associated probability of $p < .0003$ (one-tailed test).

As this example demonstrates, ties have only a slight effect. Even when a large proportion of the scores are tied (this example had over 90 per cent of its observations involved in ties) the effect is practically negligible. Observe, however, that the magnitude of the correction factor, ΣT, depends importantly on the *length* of the various ties, i.e., on the size of the various t's. Thus a tie of length 4 contributes 5.0 to ΣT in this example, whereas two ties of length 2 contribute together only 1.0 (that is, $.5 + .5$) to ΣT. And a tie of length 6 contributes 17.5, whereas two of length 3 contribute together only $2.0 + 2.0 = 4.0$.

When the correction is employed, it tends to *increase* the value of z slightly, making it more significant. Therefore when we do not correct for ties our test is "conservative" in that the value of p will be slightly inflated. That is, the value of the probability associated with the observed data under H_0 will be slightly larger than that which would be found were the correction employed. The writer's recommendation is that one should correct for ties only if the proportion of ties is quite large, if some of the t's are large, or if the p which is obtained without the correction is very close to one's previously set value of α.

Summary of procedure. These are the steps in the use of the Mann-Whitney U test:

1. Determine the values of n_1 and n_2. n_1 = the number of cases in the smaller group; n_2 = the number of cases in the larger group.
2. Rank together the scores for both groups, assigning the rank of 1 to the score which is algebraically lowest. Ranks range from 1 to $N = n_1 + n_2$. Assign tied observations the average of the tied ranks.
3. Determine the value of U either by the counting method or by applying formula (6.7*a*) or (6.7*b*).
4. The method for determining the significance of the observed value of U depends on the size of n_2:
   a. If n_2 is 8 or less, the exact probability associated with a value as small as the observed value of U is shown in Table J. For a two-tailed test, double the value of p shown in that table. If your observed U is not shown in Table J, it is U' and should be transformed to U by formula (6.6).
   b. If n_2 is between 9 and 20, the significance of any observed value of U may be determined by reference to Table K. If your observed value of U is larger than $n_1n_2/2$, it is U'; apply formula (6.6) for a transformation.
   c. If n_2 is larger than 20, the probability associated with a value as extreme as the observed value of U may be determined by computing the value of z as given by formula (6.8), and testing this value by referring to Table A. For a two-tailed test, double the p shown in that table. If the proportion of ties is very large or if the obtained p is very close to α, apply the correction for ties, i.e., use formula (6.9) rather than (6.8).
5. If the observed value of U has an associated probability equal to or less than α, reject H_0 in favor of H_1.

Power-Efficiency

If the Mann-Whitney test is applied to data which might properly be analyzed by the most powerful parametric test, the t test, its power-efficiency approaches $3/\pi = 95.5$ per cent as N increases (Mood, 1954), and is close to 95 per cent even for moderate-sized samples. It is therefore an excellent alternative to the t test, and of course it does not have the restrictive assumptions and requirements associated with the t test.

Whitney (1948, pp. 51–56) gives examples of distributions for which the U test is superior to its parametric alternative, i.e., for which the U test has *greater* power to reject H_0.

References

For discussions of the Mann-Whitney test,[1] the reader may refer to Auble (1953), Mann and Whitney (1947), Whitney (1948), and Wilcoxon (1945).

THE KOLMOGOROV-SMIRNOV TWO-SAMPLE TEST

Function and Rationale

The Kolmogorov-Smirnov two-sample test is a test of whether two independent samples have been drawn from the same population (or from populations with the same distribution). The two-tailed test is sensitive to any kind of difference in the distributions from which the two samples were drawn—differences in location (central tendency), in dispersion, in skewness, etc. The one-tailed test is used to decide whether or not the values of the population from which one of the samples was drawn are stochastically larger than the values of the population from which the other sample was drawn, e.g., to test the prediction that the scores of an experimental group will be "better" than those of the control group.

Like the Kolmogorov-Smirnov one-sample test (pages 47 to 52), this two-sample test is concerned with the agreement between two cumulative distributions. The one-sample test is concerned with the agreement between the distribution of a set of sample values and some specified theoretical distribution. The two-sample test is concerned with the agreement between two sets of sample values.

If the two samples have in fact been drawn from the same population distribution, then the cumulative distributions of both samples may be expected to be fairly close to each other, inasmuch as they both should show only random deviations from the population distribution. If the

[1] Two nonparametric statistical tests which are essentially equivalent to the Mann-Whitney U test have been reported in the literature and should be mentioned here. The first of these is due to Festinger (1946). He gives a method for calculating exact probabilities and gives a two-tailed table for the .05 and .01 levels of significance for $n_1 + n_2 \leq 40$, when $n_1 \leq 12$. In addition, for n_1 from 13 to 15, values are given up to $n_1 + n_2 = 30$.

The second test is due to White (1952), who gives a method essentially the same as the Mann-Whitney test except that rather than U it employs R (the sum of the ranks of one of the groups) as its statistic. White offers two-tailed tables for the .05, .01, and .001 levels of significance for $n_1 + n_2 \leq 30$.

Inasmuch as these tests are linearly related to the Mann-Whitney test (and therefore will yield the same results in the test of H_0 for any given batch of data), it was felt that inclusion of complete discussions of them in this text would introduce unnecessary redundancy.

TABLE J. TABLE OF PROBABILITIES ASSOCIATED WITH VALUES AS SMALL AS OBSERVED VALUES OF U IN THE MANN-WHITNEY TEST*

$n_2 = 3$

U \ n_1	1	2	3
0	.250	.100	.050
1	.500	.200	.100
2	.750	.400	.200
3		.600	.350
4			.500
5			.650

$n_2 = 4$

U \ n_1	1	2	3	4
0	.200	.067	.028	.014
1	.400	.133	.057	.029
2	.600	.267	.114	.057
3		.400	.200	.100
4		.600	.314	.171
5			.429	.243
6			.571	.343
7				.443
8				.557

$n_2 = 5$

U \ n_1	1	2	3	4	5
0	.167	.047	.018	.008	.004
1	.333	.095	.036	.016	.008
2	.500	.190	.071	.032	.016
3	.667	.286	.125	.056	.028
4		.429	.196	.095	.048
5		.571	.286	.143	.075
6			.393	.206	.111
7			.500	.278	.155
8			.607	.365	.210
9				.452	.274
10				.548	.345
11					.421
12					.500
13					.579

$n_2 = 6$

U \ n_1	1	2	3	4	5	6
0	.143	.036	.012	.005	.002	.001
1	.286	.071	.024	.010	.004	.002
2	.428	.143	.048	.019	.009	.004
3	.571	.214	.083	.033	.015	.008
4		.321	.131	.057	.026	.013
5		.429	.190	.086	.041	.021
6		.571	.274	.129	.063	.032
7			.357	.176	.089	.047
8			.452	.238	.123	.066
9			.548	.305	.165	.090
10				.381	.214	.120
11				.457	.268	.155
12				.545	.331	.197
13					.396	.242
14					.465	.294
15					.535	.350
16						.409
17						.469
18						.531

* Reproduced from Mann, H. B., and Whitney, D. R. 1947. On a test of whether one of two random variables is stochastically larger than the other. *Ann. Math. Statist.*, 18, 52–54, with the kind permission of the authors and the publisher.

TABLE J. TABLE OF PROBABILITIES ASSOCIATED WITH VALUES AS SMALL AS OBSERVED VALUES OF U IN THE MANN-WHITNEY TEST* (*Continued*)

$n_2 = 7$

U \ n_1	1	2	3	4	5	6	7
0	.125	.028	.008	.003	.001	.001	.000
1	.250	.056	.017	.006	.003	.001	.001
2	.375	.111	.033	.012	.005	.002	.001
3	.500	.167	.058	.021	.009	.004	.002
4	.625	.250	.092	.036	.015	.007	.003
5		.333	.133	.055	.024	.011	.006
6		.444	.192	.082	.037	.017	.009
7		.556	.258	.115	.053	.026	.013
8			.333	.158	.074	.037	.019
9			.417	.206	.101	.051	.027
10			.500	.264	.134	.069	.036
11			.583	.324	.172	.090	.049
12				.394	.216	.117	.064
13				.464	.265	.147	.082
14				.538	.319	.183	.104
15					.378	.223	.130
16					.438	.267	.159
17					.500	.314	.191
18					.562	.365	.228
19						.418	.267
20						.473	.310
21						.527	.355
22							.402
23							.451
24							.500
25							.549

* Reproduced from Mann, H. B., and Whitney, D. R. 1947. On a test of whether of two random variables is stochastically larger than the other. *Ann. Math. tist.*, 18, 52-54, with the kind permission of the authors and the publisher.

* 8 upgradient wells
3 downgradient wells

TABLE J. TABLE OF PROBABILITIES ASSOCIATED WITH VALUES AS SMALL AS OBSERVED VALUES OF U IN THE MANN-WHITNEY TEST* (*Continued*)

$n_2 = 8$

U \ n_1	1	2	3	4	5	6	7	8	t	Normal
0	.111	.022	.006	.002	.001	.000	.000	.000	3.308	.001
1	.222	.044	.012	.004	.002	.001	.000	.000	3.203	.001
2	.333	.089	.024	.008	.003	.001	.001	.000	3.098	.001
3	.444	.133	.042	.014	.005	.002	.001	.001	2.993	.001
4	.556	.200	.067	.024	.009	.004	.002	.001	2.888	.002
5		.267	.097	.036	.015	.006	.003	.001	2.783	.003
6		.356	.139	.055	.023	.010	.005	.002	2.678	.004
7		.444	.188	.077	.033	.015	.007	.003	2.573	.005
8		.556	.248	.107	.047	.021	.010	.005	2.468	.007
9			.315	.141	.064	.030	.014	.007	2.363	.009
10			.387	.184	.085	.041	.020	.010	2.258	.012
11			.461	.230	.111	.054	.027	.014	2.153	.016
12			.539	.285	.142	.071	.036	.019	2.048	.020
13				.341	.177	.091	.047	.025	1.943	.026
14				.404	.217	.114	.060	.032	1.838	.033
15				.467	.262	.141	.076	.041	1.733	.041
16				.533	.311	.172	.095	.052	1.628	.052
17					.362	.207	.116	.065	1.523	.064
18					.416	.245	.140	.080	1.418	.078
19					.472	.286	.168	.097	1.313	.094
20					.528	.331	.198	.117	1.208	.113
21						.377	.232	.139	1.102	.135
22						.420	.268	.164	.998	.159
23						.475	.306	.191	.893	.185
24						.525	.347	.221	.788	.215
25							.389	.253	.683	.247
26							.433	.287	.578	.282
27							.478	.323	.473	.318
28							.522	.360	.368	.356
29								.399	.263	.396
30								.439	.158	.437
31								.480	.052	.481
32								.520		

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Table K. Table of Critical Values of U in the Mann-Whitney Test*

Table K_I. Critical Values of U for a One-tailed Test at $\alpha = .001$ or for a Two-tailed Test at $\alpha = .002$

n_1 \ n_2	9	10	11	12	13	14	15	16	17	18	19	20
1												
2												
3									0	0	0	0
4		0	0	0	1	1	1	2	2	3	3	3
5	1	1	2	2	3	3	4	5	5	6	7	7
6	2	3	4	4	5	6	7	8	9	10	11	12
7	3	5	6	7	8	9	10	11	13	14	15	16
8	5	6	8	9	11	12	14	15	17	18	20	21
9	7	8	10	12	14	15	17	19	21	23	25	26
10	8	10	12	14	17	19	21	23	25	27	29	32
11	10	12	15	17	20	22	24	27	29	32	34	37
12	12	14	17	20	23	25	28	31	34	37	40	42
13	14	17	20	23	26	29	32	35	38	42	45	48
14	15	19	22	25	29	32	36	39	43	46	50	54
15	17	21	24	28	32	36	40	43	47	51	55	59
16	19	23	27	31	35	39	43	48	52	56	60	65
17	21	25	29	34	38	43	47	52	57	61	66	70
18	23	27	32	37	42	46	51	56	61	66	71	76
19	25	29	34	40	45	50	55	60	66	71	77	82
20	26	32	37	42	48	54	59	65	70	76	82	88

* Adapted and abridged from Tables 1, 3, 5, and 7 of Auble, D. 1953. Extended tables for the Mann-Whitney statistic. *Bulletin of the Institute of Educational Research at Indiana University*, 1, No. 2, with the kind permission of the author and the publisher.

Table K. Table of Critical Values of U in the Mann-Whitney Test* *(Continued)*

Table K_{II}. Critical Values of U for a One-tailed Test at $\alpha = .01$ or for a Two-tailed Test at $\alpha = .02$

n_1 \ n_2	9	10	11	12	13	14	15	16	17	18	19	20
1												
2					0	0	0	0	0	0	1	1
3	1	1	1	2	2	2	3	3	4	4	4	5
4	3	3	4	5	5	6	7	7	8	9	9	10
5	5	6	7	8	9	10	11	12	13	14	15	16
6	7	8	9	11	12	13	15	16	18	19	20	22
7	9	11	12	14	16	17	19	21	23	24	26	28
8	11	13	15	17	20	22	24	26	28	30	32	34
9	14	16	18	21	23	26	28	31	33	36	38	40
10	16	19	22	24	27	30	33	36	38	41	44	47
11	18	22	25	28	31	34	37	41	44	47	50	53
12	21	24	28	31	35	38	42	46	49	53	56	60
13	23	27	31	35	39	43	47	51	55	59	63	67
14	26	30	34	38	43	47	51	56	60	65	69	73
15	28	33	37	42	47	51	56	61	66	70	75	80
16	31	36	41	46	51	56	61	66	71	76	82	87
17	33	38	44	49	55	60	66	71	77	82	88	93
18	36	41	47	53	59	65	70	76	82	88	94	100
19	38	44	50	56	63	69	75	82	88	94	101	107
20	40	47	53	60	67	73	80	87	93	100	107	114

* Adapted and abridged from Tables 1, 3, 5, and 7 of Auble, D. 1953. Extended tables for the Mann-Whitney statistic. *Bulletin of the Institute of Educational Research at Indiana University*, 1, No. 2, with the kind permission of the author and the publisher.

* Ph only

TABLE K. TABLE OF CRITICAL VALUES OF U IN THE MANN-WHITNEY TEST* (*Continued*)

Table K_{III}. Critical Values of U for a One-tailed Test at $\alpha = .025$ or for a Two-tailed Test at $\alpha = .05$

n_1 \ n_2	9	10	11	12	13	14	15	16	17	18	19	20
1												
2	0	0	0	1	1	1	1	1	2	2	2	2
3	2	3	3	4	4	5	5	6	6	7	7	8
4	4	5	6	7	8	9	10	11	11	12	13	13
5	7	8	9	11	12	13	14	15	17	18	19	20
6	10	11	13	14	16	17	19	21	22	24	25	27
7	12	14	16	18	20	22	24	26	28	30	32	34
8	15	17	19	22	24	26	29	31	34	36	38	41
9	17	20	23	26	28	31	34	37	39	42	45	48
10	20	23	26	$\boxed{29}$	33	36	39	42	45	48	52	55
11	23	26	30	33	37	40	44	47	51	55	58	62
12	26	29	33	37	41	45	49	53	57	61	65	69
13	28	33	37	41	45	50	54	59	63	67	72	76
14	31	36	40	45	50	55	59	64	67	74	78	83
15	34	39	44	49	54	59	64	70	75	80	85	90
16	37	42	47	53	59	64	70	75	81	86	92	98
17	39	45	51	57	63	67	75	81	87	93	99	105
18	42	48	55	61	67	74	80	86	93	99	106	112
19	45	52	58	65	72	78	85	92	99	106	113	119
20	48	55	62	69	76	83	90	98	105	112	119	127

* Adapted and abridged from Tables 1, 3, 5, and 7 of Auble, D. 1953. Extended tables for the Mann-Whitney statistic. *Bulletin of the Institute of Educational Research at Indiana University*, 1, No. 2, with the kind permission of the author and the publisher.

* Everything but Ph

TABLE K. TABLE OF CRITICAL VALUES OF U IN THE MANN-WHITNEY TEST* (*Continued*)

Table K_{IV}. Critical Values of U for a One-tailed Test at $\alpha = .05$ or for a Two-tailed Test at $\alpha = .10$

n_2 \ n_1	9	10	11	12	13	14	15	16	17	18	19	20
1											0	0
2	1	1	1	2	2	2	3	3	3	4	4	4
3	3	4	5	5	6	7	7	8	9	9	10	11
4	6	7	8	9	10	11	12	14	15	16	17	18
5	9	11	12	13	15	16	18	19	20	22	23	25
6	12	14	16	17	19	21	23	25	26	28	30	32
7	15	17	19	21	24	26	28	30	33	35	37	39
8	18	20	23	26	28	31	33	36	39	41	44	47
9	21	24	27	30	33	36	39	42	45	48	51	54
10	24	27	31	$\boxed{34}$	37	41	44	48	51	55	58	62
11	27	31	34	38	42	46	50	54	57	61	65	69
12	30	34	38	42	47	51	55	60	64	68	72	77
13	33	37	42	47	51	56	61	65	70	75	80	84
14	36	41	46	51	56	61	66	71	77	82	87	92
15	39	44	50	55	61	66	72	77	83	88	94	100
16	42	48	54	60	65	71	77	83	89	95	101	107
17	45	51	57	64	70	77	83	89	96	102	109	115
18	48	55	61	68	75	82	88	95	102	109	116	123
19	51	58	65	72	80	87	94	101	109	116	123	130
20	54	62	69	77	84	92	100	107	115	123	130	138

* Adapted and abridged from Tables 1, 3, 5, and 7 of Auble, D. 1953. Extended tables for the Mann-Whitney statistic. *Bulletin of the Institute of Educational Research at Indiana University*, 1, No. 2, with the kind permission of the author and the publisher.

ATTACHMENT 2

GROUNDWATER QUALITY DATA FOR RCRA MONITORING WELLS AT LANDFARMS II AND III

TABLE 1. SUMMARY OF GROUNDWATER QUALITY DATA FOR LANDFARM II - MONITORING WELLS NSF

FACILITY HESS OIL VIRGIN ISLANDS CORP. (HOVIC)
LOCATION ST. CROIX, U.S. VIRGIN ISLANDS
EPA RCRA I.D. # VID 980536080

RCRA FACILITY LANDFARM II

(1) DATE	(3) NSF-1 pH (s.u.)	(4) NSF-2 pH (s.u.)	(5) NSF-3 pH (s.u.)	(6) NSF-4 pH (s.u.)	(7) NSF-1 CONDUCTIVI (umhos/cm
12-Apr-82	7.475	7.45	7.35	7.575	22,
17-May-82	7.5	7.35	7.425	7.575	18,
02-Aug-82	7.625	7.6	7.55	7.5	20,
08-Nov-82	7.575	7.575	7.425	7.425	33,
12-Apr-83	7.5	7.3	7.2	7.475	28,
02-Jun-83	7.475	7.325	7.225	7.4	29,
27-Sep-83	7.2	7.05	7.05	7.2	19,
30-Nov-83	7.285	7.22	7.25	7.4	not tes
06-Mar-84	7.2875	7.365	7.3375	7.245	30,
12-Apr-84	7.575	7.2025	7.31	7.56	29,
03-Jun-84	7.405	7.175	7.4925	7.395	29,
20-Aug-84	7.4525	7.2975	7.0575	6.95	25,
28-Nov-84	7.5325	7.47	7.65	7.4875	21,
20-Mar-85	7.2025	6.9625	6.9975	7.0825	21,
01-Jul-85	7.5025	7.03	7.3375	7.37	23,

(8) NSF-2 CONDUCTIVITY (umhos/cm)	(9) NSF-3 CONDUCTIVITY (umhos/cm)	(10) NSF-4 CONDUCTIVITY (umhos/cm)	(11) NSF-1 TOC (mg/l)	(12) NSF-2 TOC (mg/l)	(13) NSF-3 TOC (mg/l)	(14) NSF-4 TOC (mg/l)
22,750	23,250	23,000	45	60	33.75	33.75
20,000	22,000	21,000	40	37.5	20	<20
21,500	22,500	22,500	25.75	39	33.25	25
40,000	46,500	37,000	54.75	74	37.5	55.25
45,250	49,500	54,250	7.75	21.5	17.5	4.75
45,500	48,000	51,250	<20	20	<20	<20
25,250	13,750	12,500	<20	51.75	<20	<20
not tested	not tested	not tested	not tested	not tested	not tested	not tested
41,500	44,500	48,000	<20	55	22	20
38,750	44,750	47,500	suspect data	not tested	not tested	not tested
42,250	44,000	53,000	<20	83	53	35
34,250	51,250	50,250	<20	84.75	<20	<20
39,750	39,750	46,750	<10	39	17.25	<20
48,750	44,000	47,750	26.5	40.75	16.25	<10
43,250	42,500	49,250	11.25	51.5	14.5	<10

TABLE 1. SUMMARY OF GROUNDWATER QUALITY DATA FOR LANDFARM II - MONITORING WELLS NSF

FACILITY HESS OIL VIRGIN ISLANDS CORP. (HOVIC)
LOCATION ST. CROIX, U.S. VIRGIN ISLANDS
EPA RCRA I.D. # VID 980536080

RCRA FACILITY LANDFARM II

(1) DATE	(15) NSF-1 TOX (mg/l Cl)	(16) NSF-2 TOX (mg/l Cl)	(17) NSF-3 TOX (mg/l Cl)	(18) NSF-4 TOX (mg/l Cl)	(19) NSF-] Pb (mg/l:
12-Apr-82	0.2025	0.335	0.545	0.38	<
17-May-82	0.2225	0.815	0.64	0.535	<
02-Aug-82	0.655	0.545	0.49	0.675	<
08-Nov-82	0.8475	0.7125	0.8575	0.835	<
12-Apr-83	2.71975	0.8885	4.19275	1.1695	<
02-Jun-83	0.35	1.015	0.6025	0.6525	<
27-Sep-83	0.2675	0.92	0.4625	0.3525	<
30-Nov-83	not tested	1.2475	not tested	not tested	<
06-Mar-84	0.19	0.5875	0.3425	0.21	<
12-Apr-84	not tested	not tested	not tested	not tested	suspect
03-Jun-84	0.435	1.4	0.755	0.28	<
20-Aug-84	0.435	0.335	0.2175	0.46	
28-Nov-84	0.305	0.4475	0.265	0.19	(
20-Mar-85	<0.05	0.185	0.295	0.575	<
01-Jul-85	0.0775	0.315	0.285	0.33	

(20) NSF-2 Pb (mg/l)	(21) NSF-3 Pb (mg/l)	(22) NSF-4 Pb (mg/l)	(23) NSF-1 Cr (mg/l)	(24) NSF-2 Cr (mg/l)	(25) NSF-3 Cr (mg/l)	(26) NSF-4 Cr (mg/l)
<0.02	<0.02	<0.02	<0.05	<0.05	<0.05	<0.05
<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
<0.01	<0.01	<0.01	<0.015	<0.015	<0.015	<0.015
<0.02	<0.02	<0.02	<0.05	<0.05	<0.05	<0.05
<0.02	<0.02	<0.02	<0.05	<0.05	<0.05	<0.05
<0.02	<0.02	<0.02	<0.05	<0.05	<0.05	<0.05
<0.02	<0.02	<0.02	<0.005	<0.005	<0.005	<0.005
suspect data	suspect data	suspect data	suspect data	suspect data	suspect data	suspect data
<0.02	<0.02	<0.02	<0.005	<0.005	<0.005	<0.005
0.02	0.02	0.02	<0.005	<0.005	<0.005	<0.005
<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

TABLE 2. SUMMARY OF WATER QUALITY DATA FOR LANDFARM III - MONITORING WELLS SSF

FACILITY : HESS OIL VIRGIN ISLANDS CORP. (HOVIC)
LOCATION : ST. CROIX, U.S. VIRGIN ISLANDS
EPA RCRA I.D. # : VID 980536080

RCRA FACILITY : LANDFARM III

(1) DATE	(3) SSF-1 pH (s.u.)	(4) SSF-2 pH (s.u.)	(5) SSF-3 pH (s.u.)	(6) SSF-4 pH (s.u.)	(7) SSF-1 CONDUCTIVI (umhos/cr
12-Apr-82	7.55	7.45	7.55	7.175	2
17-May-82	7.5	7.375	7.525	7.375	2
02-Aug-82	7.425	7.4	7.525	7.425	2
08-Nov-82	7.45	7.35	7.575	7.475	4
12-Apr-83	7.3	7.35	7.5	7.3	4
02-Jun-83	7.375	7.425	7.55	7.3	4
27-Sep-83	7.15	7.175	7.4	7.1	2
30-Nov-83	7.34	7.21	not tested	7.2175	not test
06-Mar-84	7.125	7.3425	7.3725	7.4275	4
12-Apr-84	7.7925	7.7925	not tested	not tested	4
03-Jun-84	7.3625	7.5	7.4625	7.4125	5
20-Aug-84	6.9775	7.225	7.1575	6.95	5
28-Nov-84	7.4325	7.535	7.5475	7.4725	4
20-Mar-85	6.8725	7.005	7.015	6.885	4
01-Jul-85	7.0775	7.2	7.3375	7.1275	4

(8) SSF-2 CONDUCTIVITY (umhos/cm)	(9) SSF-3 CONDUCTIVITY (umhos/cm)	(10) SSF-4 CONDUCTIVITY (umhos/cm)	(11) SSF-1 TOC (mg/l)	(12) SSF-2 TOC (mg/l)	(13) SSF-3 TOC (mg/l)	(14) SSF-4 TOC (mg/l)
23500	24250	23250	26.25	30	28.75	35
20750	18750	19500	20	20	<20	26.25
22000	20750	21750	27	21.5	20	23.5
44000	34750	51500	45	57	34	52.5
43750	33750	40750	<1	<1	<1	10.25
40500	33500	40000	<20	<20	<20	<20
24750	47000	26000	<20	<20	<20	<20
not tested	23250	not tested	not tested	not tested	not tested	not tested
40500	40750	47500	<20	<20	<20	<20
40500	38250	42500	not tested	not tested	not tested	not tested
43750	39000	44750	28.25	<20	<20	<20
43750	41250	30750	<20	<20	<20	<20
42000	33250	37750	<10	<10	<10	<10
42500	36500	44000	<10	<10	<10	<10
42000	35500	43000	<10	<10	<10	<10

TABLE 2. SUMMARY OF WATER QUALITY DATA FOR LANDFARM III - MONITORING WELLS SSF

FACILITY : HESS OIL VIRGIN ISLANDS CORP. (HOVIC)
LOCATION : ST. CROIX, U.S. VIRGIN ISLANDS
EPA RCRA I.D. # : VID 980536080

RCRA FACILITY : LANDFARM III

(1) DATE	(15) SSF-1 TOX (mg/l Cl)	(16) SSF-2 TOX (mg/l Cl)	(17) SSF-3 TOX (mg/l Cl)	(18) SSF-4 TOX (mg/l Cl)	(19) SSF-1 Pb (mg/l)
12-Apr-82	0.5525	0.325	0.505	0.3675	<0
17-May-82	0.48	0.32	0.4075	0.6025	<0.
02-Aug-82	1.2675	0.6325	0.715	1.055	<0
08-Nov-82	0.7025	0.46	0.5	0.3625	<0.
12-Apr-83	0.842	3.43025	1.62425	1.2855	<0
02-Jun-83	0.6425	0.6325	0.715	0.56	<0.
27-Sep-83	0.275	0.2875	0.24	0.2475	<0
30-Nov-83	not tested	not tested	not tested	not tested	<0
06-Mar-84	0.18	0.27	0.1725	0.1575	<0
12-Apr-84	not tested	not tested	not tested	not tested	suspect da
03-Jun-84	0.19	0.37	0.4225	0.35	0
20-Aug-84	<0.20	<0.20	<0.20	<0.20	0
28-Nov-84	0.2925	0.1875	0.225	0.1525	<0
20-Mar-85	0.0725	0.08	0.1175	0.2025	<0
01-Jul-85	0.22	0.1975	0.1225	0.205	<0

(20) SSF-2 Pb (mg/l)	(21) SSF-3 Pb (mg/l)	(22) SSF-4 Pb (mg/l)	(23) SSF-1 Cr (mg/l)	(24) SSF-2 Cr (mg/l)	(25) SSF-3 Cr (mg/l)	(26) SSF-4 Cr (mg/l)
<0.04	<0.04	<0.04	<0.05	<0.05	<0.05	<0.05
<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
<0.01	<0.01	<0.01	<0.015	<0.015	<0.015	<0.015
<0.02	<0.02	<0.02	<0.05	<0.05	<0.05	<0.05
<0.02	<0.02	<0.02	<0.05	<0.05	<0.05	<0.05
<0.02	<0.02	<0.02	<0.05	<0.05	<0.05	<0.05
<0.02	<0.02	<0.02	<0.005	0.016	0.022	<0.005
spect data	suspect data	suspect data	suspect data	suspect data	suspect data	suspect data
<0.02	<0.02	<0.02	<0.005	<0.005	<0.005	<0.005
0.02	0.02	0.02	<0.005	<0.005	<0.005	<0.005
<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

TABLE 3. GROUNDWATER QUALITY DATA FOR LANDFARM II - MONITORING WELLS NSF

FACILITY : HESS OIL VIRGIN ISLANDS CORP. (HOVIC)
LOCATION : ST. CROIX, U.S. VIRGIN ISLANDS
EPA RCRA I.D. # : VID 980536080

RCRA FACILITY : LANDFARM II

(1) DATE	(2) LABORATORY	(3) NSF-1 pH (s.u.)	(4) NSF-2 pH (s.u.)	(5) NSF-3 pH (s.u.)
12-Apr-82	HOVIC, AWARE	7.4	7.4	7.3
		7.5	7.5	7.3
		7.5	7.5	7.4
		7.5	7.4	7.4
17-May-82	HOVIC, AWARE	7.5	7.4	7.4
		7.5	7.3	7.5
		7.5	7.4	7.4
		7.5	7.3	7.4
02-Aug-82	HOVIC, AWARE	7.6	7.7	7.7
		7.5	7.5	7.4
		7.7	7.6	7.6
		7.7	7.6	7.5
08-Nov-82	HOVIC, AWARE	7.6	7.6	7.4
		7.4	7.6	7.4
		7.5	7.4	7.6
		7.8	7.7	7.3
12-Apr-83	HOVIC, AHC, ETC	7.5	7.3	7.2
		7.5	7.3	7.2
		7.5	7.3	7.2
		7.5	7.3	7.2
02-Jun-83	HOVIC, AWARE	7.4	7.3	7.3
		7.5	7.4	7.2
		7.5	7.3	7.2
		7.5	7.3	7.2
27-Sep-83	HOVIC, AWARE	7.2	7.0	7.0
		7.2	7.0	7.1
		7.2	7.1	7.0
		7.2	7.1	7.1
30-Nov-83	HOVIC, AWARE, ETC	7.26	7.21	7.22
		7.27	7.22	7.23
		7.30	7.22	7.27
		7.31	7.23	7.28

	(7) NSF-1 CONDUCTIVITY (umhos/cm)	(8) NSF-2 CONDUCTIVITY (umhos/cm)	(9) NSF-3 CONDUCTIVITY (umhos/cm)	(10) NSF-4 CONDUCTIVITY (umhos/cm)	(11) NSF-1 TOC (mg/l)	(12) NSF-2 TOC (mg/l)	(13) NSF-3 TOC (mg/l)	(14) NSF-4 TOC (mg/l)
7.6	23,000	24,000	24,000	23,000	40	60	30	35
7.6	21,000	22,000	24,000	24,000	50	65	30	35
7.5	21,000	23,000	22,000	23,000	45	60	35	30
7.6	23,000	22,000	23,000	22,000	45	55	40	35
7.6	18,000	20,000	21,000	20,000	40	40	20	<20
7.6	19,000	20,000	22,000	21,000	40	40	20	<20
7.6	18,000	20,000	23,000	20,000	40	40	20	<20
7.5	19,000	20,000	22,000	23,000	40	30	20	<20
7.5	20,000	22,000	23,000	22,000	23	38	25	25
'.4	22,000	22,000	23,000	23,000	25	40	33	25
'.6	20,000	20,000	22,000	23,000	25	38	40	25
'.5	21,000	22,000	22,000	22,000	30	40	35	25
'.4	32,000	40,000	45,000	37,000	60	78	40	55
'.4	34,000	40,000	47,000	37,000	53	78	40	53
'.6	34,000	40,000	47,000	37,000	53	70	35	60
'.3	35,000	40,000	47,000	37,000	53	70	35	53
'.5	28,000	44,000	48,000	54,000	9	22	17	3
.4	28,000	46,000	50,000	55,000	7	20	17	4
'.5	29,000	46,000	50,000	54,000	6	22	17	6
.5	29,000	45,000	50,000	54,000	9	22	19	6
.5	30,000	44,000	47,000	50,000	<20	20	<20	<20
.4	28,000	45,000	47,000	51,000	<20	20	<20	<20
.3	29,000	46,000	49,000	52,000	<20	20	<20	<20
.4	29,000	47,000	49,000	52,000	<20	20	20	<20
.2	20,000	26,000	14,000	12,000	<20	45	<20	<20
.2	21,000	28,000	13,000	12,000	<20	60	<20	<20
.2	18,000	24,000	14,000	13,000	<20	53	20	<20
.2	18,000	23,000	14,000	13,000	<20	49	20	<20
37 18 12 3	not tested	not tested	not tested	not tested	not tested	not tested	not tested	not tested

TABLE 3. GROUNDWATER QUALITY DATA FOR LANDFARM II - MONITORING WELLS NSF

FACILITY : HESS OIL VIRGIN ISLANDS CORP. (HOVIC)
LOCATION : ST. CROIX, U.S. VIRGIN ISLANDS
EPA RCRA I.D. # : VID 980536080

RCRA FACILITY : LANDFARM II

(1) DATE	(2) LABORATORY	(3) NSF-1 pH (s.u.)	(4) NSF-2 pH (s.u.)	(5) NSF-3 pH (s.u.)
06-Mar-84	HOVIC, AWARE	7.22	7.32	7.29
		7.31	7.39	7.35
		7.32	7.40	7.36
		7.30	7.35	7.35
12-Apr-84	HOVIC, OTHERS	7.58	7.21	7.31
		7.59	7.21	7.30
		7.57	7.20	7.31
		7.56	7.19	7.32
03-Jun-84	HOVIC, AWARE	7.32	7.15	7.45
		7.36	7.15	7.50
		7.45	7.20	7.50
		7.49	7.20	7.52
20-Aug-84	HOVIC, AWARE, IT ANALYTICAL	7.50	7.28	7.14
		7.51	7.24	7.15
		7.39	7.33	6.96
		7.41	7.34	6.98
28-Nov-84	HOVIC, AHC, AWARE	7.31	7.45	7.46
		7.66	7.49	7.76
		7.60	7.45	7.70
		7.56	7.49	7.68
20-Mar-85	HOVIC, AHC, AWARE	7.21	6.92	6.94
		7.20	6.96	7.00
		7.20	6.98	7.02
		7.20	6.99	7.03
01-Jul-85	HOVIC, AHC, AWARE	7.63	7.07	7.17
		7.48	7.04	7.17
		7.41	7.00	7.48
		7.49	7.01	7.53

I	(7) NSF-1 CONDUCTIVITY (umhos/cm)	(8) NSF-2 CONDUCTIVITY (umhos/cm)	(9) NSF-3 CONDUCTIVITY (umhos/cm)	(10) NSF-4 CONDUCTIVITY (umhos/cm)	(11) NSF-1 TOC (mg/l)	(12) NSF-2 TOC (mg/l)	(13) NSF-3 TOC (mg/l)	(14) NSF-4 TOC (mg/l)
7.22	30,000	41,000	45,000	48,000	<20	56	20	20
7.24	30,000	42,000	44,000	48,000	<20	56	24	20
7.25	30,000	41,000	45,000	48,000	<20	54	24	20
7.27	30,000	42,000	44,000	48,000	<20	54	20	20
7.58	28,000	37,000	44,000	46,000	suspect data	not tested	not tested	not tested
7.52	30,000	39,000	46,000	49,000				
7.59	31,000	40,000	45,000	48,000				
'.55	29,000	39,000	44,000	47,000				
'.38	31,000	40,000	42,000	54,000	<20	83	53	35
'.40	31,000	40,000	42,000	53,000	<20	83	53	35
'.40	28,000	45,000	46,000	52,000	<20	83	53	35
.40	29,000	44,000	46,000	53,000	<20	83	53	35
.96	27,000	34,000	55,000	52,000	<20	86	<20	<20
.97	28,000	33,000	56,000	52,000	<20	85	<20	<20
.93	23,000	36,000	48,000	49,000	<20	84	<20	<20
.94	25,000	34,000	46,000	48,000	<20	84	<20	<20
.50	21,000	40,000	39,000	48,000	10	40	20	<20
.38	23,000	41,000	42,000	46,000	<10	38	13	<20
.52	22,000	40,000	40,000	47,000	<10	39	18	<20
.55	21,000	38,000	38,000	46,000	<10	39	18	<20
.07	21,000	49,000	43,000	45,000	33	43	18	<10
07	21,000	50,000	44,000	49,000	26	45	16	<10
09	22,000	48,000	45,000	49,000	24	36	16	<10
10	22,000	48,000	44,000	48,000	23	39	15	<10
39	24,000	44,000	42,000	49,000	13	48	14	<10
42	23,000	43,000	43,000	50,000	10	50	14	<10
33	23,000	43,000	43,000	49,000	12	50	16	<10
34	23,000	43,000	42,000	49,000	10	58	14	<10

TABLE 3. GROUNDWATER QUALITY DATA FOR LANDFARM II - MONITORING WELLS NSF

FACILITY : HESS OIL VIRGIN ISLANDS CORP. (HOVIC)
LOCATION : ST. CROIX, U.S. VIRGIN ISLANDS
EPA RCRA I.D. # : VID 980536080

RCRA FACILITY : LANDFARM II

(1) DATE	(15) NSF-1 TOX (mg/l Cl)	(16) NSF-2 TOX (mg/l Cl)	(17) NSF-3 TOX (mg/l Cl)	(18) NSF-4 TOX (mg/l Cl)	(N (m
12-Apr-82	0.20	0.24	0.64	0.34	
	0.17	0.37	0.51	0.45	
	0.24	0.28	0.46	0.30	
	0.20	0.45	0.57	0.43	
17-May-82	0.17	0.49	0.23	0.30	
	0.26	0.86	0.64	0.63	
	0.17	0.93	0.69	0.84	
	0.29	0.98	1.00	0.37	
02-Aug-82	0.52	0.55	0.51	0.57	
	0.79	0.54	0.51	0.66	
	0.79	0.52	0.44	0.71	
	0.52	0.57	0.50	0.76	
08-Nov-82	0.82	0.69	0.83	0.85	
	0.82	0.75	0.80	0.72	
	0.89	0.71	0.77	0.95	
	0.86	0.7	1.03	0.82	
12-Apr-83	2.640	0.788	4.068	1.149	
	2.829	0.923	4.294	1.172	
	2.784	0.952	4.186	1.201	
	2.626	0.891	4.223	1.156	
02-Jun-83	0.35	1.00	0.59	0.68	
	0.38	1.03	0.60	0.55	
	0.31	1.00	0.59	0.80	
	0.36	1.03	0.63	0.58	
27-Sep-83	0.28	0.88	0.54	0.29	
	0.25	0.94	0.40	0.36	
	0.28	0.95	0.46	0.36	
	0.26	0.91	0.45	0.40	
30-Nov-83	not tested	1.240	not tested	not tested	
		1.240			
		1.260			
		1.250			

	(20) NSF-2 Pb (mg/l)	(21) NSF-3 Pb (mg/l)	(22) NSF-4 Pb (mg/l)	(23) NSF-1 Cr (mg/l)	(24) NSF-2 Cr (mg/l)	(25) NSF-3 Cr (mg/l)	(26) NSF-4 Cr (mg/l)
.02	<0.02	<0.02	<0.02	<0.05	<0.05	<0.05	<0.05
.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
0	<10	<10	<10	<15	<15	<15	<15
2	<0.02	<0.02	<0.02	<0.05	<0.05	<0.05	<0.05
2	<0.02	<0.02	<0.02	<0.05	<0.05	<0.05	<0.05
	<0.02	<0.02	<0.02	<0.05	<0.05	<0.05	<0.05

TABLE 3. GROUNDWATER QUALITY DATA FOR LANDFARM II - MONITORING WELLS NSF

FACILITY : HESS OIL VIRGIN ISLANDS CORP. (HOVIC)
LOCATION : ST. CROIX, U.S. VIRGIN ISLANDS
EPA RCRA I.D. # : VID 980536080

RCRA FACILITY : LANDFARM II

(1) DATE	(15) NSF-1 TOX (mg/l Cl)	(16) NSF-2 TOX (mg/l Cl)	(17) NSF-3 TOX (mg/l Cl)	(18) NSF-4 TOX (mg/l Cl)	
06-Mar-84	0.18	0.59	0.33	0.23	
	0.19	0.59	0.35	0.22	
	0.19	0.59	0.32	0.21	
	0.20	0.58	0.37	0.18	
12-Apr-84	not tested	not tested	not tested	not tested	susp
03-Jun-84	0.44	1.39	0.85	0.35	
	0.41	1.42	0.64	0.28	
	0.47	1.42	0.79	0.22	
	0.42	1.37	0.74	0.27	
20-Aug-84	0.49	0.28	0.24	0.56	
	0.41	0.36	0.20	0.37	
	0.43	0.35	0.25	0.39	
	0.41	0.35	0.18	0.52	
28-Nov-84	0.27	0.40	0.26	0.18	
	0.28	0.48	0.27	0.18	
	0.37	0.46	0.26	0.19	
	0.30	0.45	0.27	0.21	
20-Mar-85	<0.05	0.18	0.31	0.66	
	<0.05	0.17	0.31	0.63	
	<0.05	0.13	0.29	0.55	
	<0.05	0.26	0.27	0.46	
01-Jul-85	0.07	0.30	0.28	0.51	
	0.08	0.23	0.27	0.28	
	0.08	0.35	0.34	0.26	
	0.08	0.38	0.25	0.27	

	(20) NSF-2 Pb (mg/l)	(21) NSF-3 Pb (mg/l)	(22) NSF-4 Pb (mg/l)	(23) NSF-1 Cr (mg/l)	(24) NSF-2 Cr (mg/l)	(25) NSF-3 Cr (mg/l)	(26) NSF-4 Cr (mg/l)
).02	<0.02	<0.02	<0.02	<.005	<.005	<.005	0.016
ta	suspect data	suspect data	suspect data	suspect data	suspect data	suspect data	suspect data
	<.02	<.02	<.02	<.005	<.005	<.005	<.005
01	0.02	0.02	0.02	<.005	<.005	<.005	<.005
12	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

TABLE 4. WATER QUALITY DATA FOR LANDFARM III - MONITORING WELLS SSF

FACILITY : HESS OIL VIRGIN ISLANDS CORP. (HOVIC)
LOCATION : ST. CROIX, U.S. VIRGIN ISLANDS
EPA RCRA I.D. # : VID 980536080

RCRA FACILITY : LANDFARM III

(1) DATE	(2) LABORATORY	(3) SSF-1 pH (s.u.)	(4) SSF-2 pH (s.u.)	(5) SSF-3 pH (s.u.)	S (s
12-Apr-82	HOVIC, AWARE	7.5	7.4	7.5	
		7.6	7.5	7.6	
		7.5	7.4	7.5	
		7.6	7.5	7.6	
17-May-82	HOVIC, AWARE	7.5	7.3	7.5	
		7.5	7.4	7.6	
		7.5	7.3	7.5	
		7.5	7.5	7.5	
02-Aug-82	HOVIC, AWARE	7.4	7.4	7.6	
		7.4	7.4	7.5	
		7.5	7.4	7.5	
		7.4	7.4	7.5	
08-Nov-82	HOVIC, AWARE	7.5	7.5	7.6	
		7.3	7.4	7.6	
		7.4	7.3	7.4	
		7.6	7.2	7.7	
12-Apr-83	HOVIC, AHC, ETC	7.3	7.3	7.5	
		7.3	7.3	7.5	
		7.3	7.4	7.5	
		7.3	7.4	7.5	
02-Jun-83	HOVIC, AWARE	7.5	7.4	7.5	
		7.4	7.5	7.6	
		7.3	7.4	7.6	
		7.3	7.4	7.5	
27-Sep-83	HOVIC, AWARE	7.1	7.1	7.4	
		7.1	7.2	7.4	
		7.2	7.2	7.4	
		7.2	7.2	7.4	
30-Nov-83	HOVIC, AWARE, ETC	7.32	7.2	not tested	
		7.33	7.21		
		7.35	7.21		
		7.36	7.22		

	(7) SSF-1 CONDUCTIVITY (umhos/cm)	(8) SSF-2 CONDUCTIVITY (umhos/cm)	(9) SSF-3 CONDUCTIVITY (umhos/cm)	(10) SSF-4 CONDUCTIVITY (umhos/cm)	(11) SSF-1 TOC (mg/l)	(12) SSF-2 TOC (mg/l)	(13) SSF-3 TOC (mg/l)	(14) SSF-4 TOC (mg/l)
7.2	25,000	23,000	25,000	25,000	25	30	30	30
7.2	23,000	25,000	23,000	23,000	30	30	30	40
7.2	23,000	22,000	24,000	23,000	25	30	30	35
7.1	24,000	24,000	25,000	22,000	25	30	25	35
7.4	22,000	21,000	18,000	19,000	20	20	<20	30
7.4	21,000	21,000	19,000	20,000	20	20	<20	25
7.4	22,000	21,000	20,000	19,000	20	20	<20	25
7.3	21,000	20,000	18,000	20,000	20	20	<20	25
.5	22,000	22,000	20,000	22,000	30	20	20	23
.4	21,000	22,000	21,000	22,000	30	23	20	25
.4	20,000	21,000	20,000	21,000	23	23	20	23
.4	23,000	23,000	22,000	22,000	25	20	20	23
.5	44,000	44,000	34,000	50,000	50	60	35	55
.6	43,000	44,000	35,000	52,000	50	60	33	55
.4	44,000	44,000	35,000	52,000	40	55	35	50
.4	44,000	44,000	35,000	52,000	40	53	33	50
.3	47,000	42,000	35,000	40,000	1	<1	<1	9
.3	48,000	44,000	34,000	41,000	<1	<1	<1	11
.3	48,000	44,000	33,000	41,000	<1	<1	<1	11
.3	48,000	45,000	33,000	41,000	1	<1	<1	10
.3	44,000	40,000	33,000	40,000	<20	<20	<20	<20
2	42,000	40,000	33,000	40,000	<20	<20	<20	<20
4	42,000	40,000	33,000	40,000	<20	<20	<20	<20
3	45,000	42,000	35,000	40,000	<20	<20	<20	<20
1	27,000	21,000	49,000	26,000	<20	<20	<20	<20
1	25,000	21,000	49,000	26,000	<20	<20	<20	<20
1	25,000	29,000	45,000	26,000	<20	<20	<20	<20
1	27,000	28,000	45,000	26,000	<20	<20	<20	<20
2	not tested	not tested	30,000	not tested	not tested	not tested	not tested	not tested
[illegible]			18,000					
[illegible]			30,000					
[illegible]			15,000					

TABLE 4. WATER QUALITY DATA FOR LANDFARM III - MONITORING WELLS SSF

FACILITY : HESS OIL VIRGIN ISLANDS CORP. (HOVIC)
LOCATION : ST. CROIX, U.S. VIRGIN ISLANDS
EPA RCRA I.D. # : VID 980536080

RCRA FACILITY : LANDFARM III

(1) DATE	(2) LABORATORY	(3) SSF-1 pH (s.u.)	(4) SSF-2 pH (s.u.)	(5) SSF-3 pH (s.u.)	(
06-Mar-84	HOVIC, AWARE	7.09	7.32	7.25	
		7.14	7.34	7.34	
		7.13	7.36	7.37	
		7.14	7.35	7.53	
12-Apr-84	HOVIC, OTHERS	7.76	7.76	not tested	not
		7.75	7.75		
		7.83	7.83		
		7.83	7.83		
03-Jun-84	HOVIC, AWARE	7.35	7.48	7.35	
		7.35	7.50	7.40	
		7.35	7.50	7.60	
		7.40	7.52	7.50	
20-Aug-84	HOVIC, AWARE, IT ANALYTICAL	6.99	7.25	7.15	
		6.99	7.25	7.16	
		6.96	7.20	7.16	
		6.97	7.20	7.16	
28-Nov-84	HOVIC, AHC, AWARE	7.41	7.67	7.54	
		7.43	7.49	7.58	
		7.44	7.50	7.59	
		7.45	7.48	7.48	
20-Mar-85	HOVIC, AHC, AWARE	6.83	7.02	6.97	
		6.76	7.00	7.03	
		7.00	7.00	7.03	
		6.90	7.00	7.03	
01-Jul-85	HOVIC, AHC AWARE	7.19	7.26	7.38	
		7.21	7.32	7.33	
		6.92	7.10	7.31	
		6.99	7.12	7.33	

	(7) SSF-1 CONDUCTIVITY (umhos/cm)	(8) SSF-2 CONDUCTIVITY (umhos/cm)	(9) SSF-3 CONDUCTIVITY (umhos/cm)	(10) SSF-4 CONDUCTIVITY (umhos/cm)	(11) SSF-1 TOC (mg/l)	(12) SSF-2 TOC (mg/l)	(13) SSF-3 TOC (mg/l)	(14) SSF-4 TOC (mg/l)
7.30	45,000	40,000	41,000	48,000	<20	<20	<20	<20
7.38	44,000	41,000	40,000	47,000	<20	<20	<20	<20
7.47	44,000	40,000	41,000	48,000	<20	<20	<20	<20
7.56	45,000	41,000	41,000	47,000	<20	<20	<20	<20
ed	44,000	40,000	38,000	42,000	not tested	not tested	not tested	not tested
	45,000	41,000	38,000	43,000				
	44,000	41,000	38,000	42,000				
	43,000	40,000	39,000	43,000				
.40	51,000	45,000	40,000	45,000	30	<20	<20	<20
.45	51,000	43,000	39,000	46,000	30	<20	<20	<20
.40	50,000	44,000	38,000	44,000	28	<20	<20	<20
.40	50,000	43,000	39,000	44,000	25	<20	<20	<20
.00	50,000	42,000	43,000	29,000	<20	<20	<20	<20
.01	48,000	42,000	41,000	32,000	<20	<20	<20	<20
.89	50,000	46,000	41,000	30,000	<20	<20	<20	<20
.90	52,000	45,000	40,000	32,000	<20	<20	<20	<20
.58	45,000	42,000	34,000	38,000	<10	<10	<10	<10
.44	45,000	42,000	33,000	38,000	<10	<10	<10	<10
.45	45,000	42,000	33,000	38,000	<10	<10	<10	<10
.42	44,000	42,000	33,000	37,000	<10	<10	<10	<10
.93	47,000	41,000	36,000	46,000	<10	<10	<10	<10
.87	43,000	43,000	36,000	42,000	<10	<10	<10	<10
.87	45,000	43,000	37,000	44,000	<10	<10	<10	<10
.87	45,000	43,000	37,000	44,000	<10	<10	<10	<10
.25	46,000	42,000	35,000	44,000	<10	<10	<10	<10
.00	46,000	42,000	37,000	42,000	<10	<10	<10	<10
.12	45,000	42,000	35,000	43,000	<10	<10	<10	<10
.14	45,000	42,000	35,000	43,000	<10	<10	<10	<10

TABLE 4. WATER QUALITY DATA FOR LANDFARM III - MONITORING WELLS SSF

FACILITY : HESS OIL VIRGIN ISLANDS CORP. (HOVIC)
LOCATION : ST. CROIX, U.S. VIRGIN ISLANDS
EPA RCRA I.D. # : VID 980536080

RCRA FACILITY : LANDFARM III

(1) DATE	(2) LABORATORY	(15) SSF-1 TOX (mg/l Cl)	(16) SSF-2 TOX (mg/l Cl)	(17) SSF-3 TOX (mg/l Cl)	(18) SSF- TOX (mg/l (
12-Apr-82	HOVIC, AWARE	0.45	0.27	0.41	
		0.53	0.30	0.50	
		0.58	0.48	0.74	
		0.65	0.25	0.37	
17-May-82	HOVIC, AWARE	0.80	0.22	0.23	
		0.36	0.44	0.22	
		0.32	0.22	0.67	
		0.44	0.40	0.51	
02-Aug-82	HOVIC, AWARE	1.30	0.72	0.70	
		1.16	0.68	0.71	
		1.41	0.53	0.63	
		1.20	0.60	0.82	
08-Nov-82	HOVIC, AWARE	0.65	0.57	0.46	
		0.63	0.41	0.49	
		0.63	0.46	0.49	
		0.90	0.40	0.56	
12-Apr-83	HOVIC, AHC, ETC	0.813	3.425	1.806	1
		0.852	3.636	1.651	1
		0.829	3.403	1.560	1
		0.874	3.257	1.480	1
02-Jun-83	HOVIC, AWARE	0.46	0.65	0.78	
		0.73	0.72	0.64	
		0.73	0.57	0.74	
		0.65	0.59	0.70	
27-Sep-83	HOVIC, AWARE	0.24	0.27	0.38	
		0.28	0.24	0.16	
		0.31	0.28	0.27	
		0.27	0.36	0.15	
30-Nov-83	HOVIC, AWARE, ETC	not tested	not tested	not tested	not tes

(19) SSF-1 Pb (mg/l)	(20) SSF-2 Pb (mg/l)	(21) SSF-3 Pb (mg/l)	(22) SSF-4 Pb (mg/l)	(23) SSF-1 Cr (mg/l)	(24) SSF-2 Cr (mg/l)	(25) SSF-3 Cr (mg/l)	(26) SSF-4 Cr (mg/l)
<0.04	<0.04	<0.04	<0.04	<0.05	<0.05	<0.05	<0.05
<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
<10	<10	<10	<10	<15	<15	<15	<15
<0.02	<0.02	<0.02	<0.02	<0.05	<0.05	<0.05	<0.05
<0.02	<0.02	<0.02	<0.02	<0.05	<0.05	<0.05	<0.05
<0.02	<0.02	<0.02	<0.02	<0.05	<0.05	<0.05	<0.05

TABLE 4. WATER QUALITY DATA FOR LANDFARM III - MONITORING WELLS SSF

FACILITY : HESS OIL VIRGIN ISLANDS CORP. (HOVIC)
LOCATION : ST. CROIX, U.S. VIRGIN ISLANDS
EPA RCRA I.D. # : VID 980536080

RCRA FACILITY : LANDFARM III

(1) DATE	(2) LABORATORY	(15) SSF-1 TOX (mg/l Cl)	(16) SSF-2 TOX (mg/l Cl)	(17) SSF-3 TOX (mg/l Cl)	(18) SSF- TOX (mg/l
06-Mar-84	HOVIC, AWARE	0.19	0.24	0.15	
		0.19	0.29	0.17	
		0.17	0.27	0.19	
		0.17	0.28	0.18	
12-Apr-84	HOVIC, OTHERS	not tested	not tested	not tested	not tes
03-Jun-84	HOVIC, AWARE	0.23	0.37	0.39	
		0.16	0.39	0.36	
		0.20	0.33	0.48	
		0.17	0.39	0.46	
20-Aug-84	HOVIC, AWARE, IT ANALYTICAL	<20	<20	<20	<20
		<20	<20	<20	<20
		<20	<20	<20	<20
		<20	<20	<20	<20
28-Nov-84	HOVIC, AHC, AWARE	0.38	0.24	0.17	
		0.32	0.15	0.30	
		0.23	0.19	0.21	
		0.24	0.17	0.22	
20-Mar-85	HOVIC, AHC, AWARE	0.07	0.06	0.18	
		0.06	0.1	0.07	
		0.08	0.07	0.15	
		0.08	0.09	0.07	
01-Jul-85	HOVIC, AHC AWARE	0.20	0.20	0.13	
		0.22	0.17	0.14	
		0.26	0.22	0.12	
		0.20	0.20	0.10	

(19) SSF-1 Pb (mg/l)	(20) SSF-2 Pb (mg/l)	(21) SSF-3 Pb (mg/l)	(22) SSF-4 Pb (mg/l)	(23) SSF-1 Cr (mg/l)	(24) SSF-2 Cr (mg/l)	(25) SSF-3 Cr (mg/l)	(26) SSF-4 Cr (mg/l)
<0.02	<0.02	<0.02	<0.02	<0.005	0.016	0.022	<0.005
suspect data	suspect data	suspect data	suspect data	suspect data	suspect data	suspect data	suspect data
0.03	<0.02	<0.02	<0.02	<0.005	<0.005	<0.005	<0.005
0.01	0.02	0.02	0.02	<0.005	<0.005	<0.005	<0.005
<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010

ATTACHMENT 3

STATISTICAL CALCULATIONS

LEGEND

MODIFIED STUDENTS' T TEST

$$t^* = \sqrt{\frac{S_{dg} - \overline{X}_{bg}}{\sqrt{\frac{S_{bg}^2}{n}}}}$$

Where:

X_{dg} = ln concentration (value)in downgradient well for most recent sampling period

$\overline{X}_{bg}$ = ln mean of at least the last eight data points from one or more background wells

S_{bg}^2 = variance

n = number of upgradient data points used $8 \leq n \leq 16$

$$tc = \frac{t_{bg} \, S_{bg}{}^{z}/_{n}}{S^2_{bg/n}} = t_{bg}$$

(From Standard T-Tables 0.05 level of significance for n-1 degrees of freedom)

$t^* < t_{bg}$ There has not been a significant change in this parameter

$t^* > t_{bg}$ Most likely there has been a significant increase (or pH decrease) in this parameter

MANN-WHITNEY U TEST

(See Attachment 1 for Procedure)

JOB: HOVIC LANDFARM II

SHEET NO. 1 OF 5

CALCULATED BY: RJL DATE: 9/12/85

CHECKED BY: MRC DATE: 10/9/85

SCALE

t - TESTS FOR LANDFARM II SUMMARY

CONSTITUENT		WELLS 1	2	3	4
pH (s.u)	# OF READINGS	8	1	1	1
	MEAN	7.4053	7.03	7.3375	7.37
	S	0.1342	–	–	–
	t_*		-7.9082	-1.4289	-0.7441
	t_{comp}		2.365	2.365	2.365
	SIGNIFICANT		YES	NO	NO
CONDUCTIVITY (umhos/cm)	# OF READINGS	8	1	1	1
	MEAN	25,093.75	43,250	42,500	49250
	S	4263.5027	–	–	–
	t_*		12.0449	11.5474	16.0254
	t_{comp}		1.895	1.895	1.895
	SIGNIFICANT		YES	YES	YES
TOC (mg/l)	# OF READINGS	8	1	1	1
	MEAN	17.53	51.5	14.5	35
	S	7.332	–	–	–
	t_*		13.1044	-1.1689	6.7393
	t_{comp}		1.895	1.895	1.895
	SIGNIFICANT		YES	NO	YES
TOX (mg/l)	# OF READINGS	8	1	1	1
	MEAN	0.1991	0.315	0.285	0.33
	S	0.1707	–	–	–
	t_*		1.9204	1.4233	2.1690
	t_{comp}		1.895	1.895	1.895
	SIGNIFICANT		YES	NO	YES

JOB: HOVIC LANDFARM III

SHEET NO. 1 OF 5

CALCULATED BY: RJL DATE: 9/12/85

CHECKED BY: MRL DATE: 10/9/85

SCALE:

t-TESTS FOR LANDFARM III SUMMARY

$$t^* = \frac{\bar{X}_m - \bar{X}_B}{\sqrt{\frac{S_B^2}{n}}}$$

B = background
m = monitoring well

CONSTITUENT		WELLS 1	2	3	4
pH (s.u.)	# OF READINGS	8	1	1	1
	MEAN	7.2475	7.2	7.3375	7.1275
	S	0.2953	—	—	—
	t_*		0.4549	0.8620	1.1493
	t_{comp}		2.365	2.365	2.365
	SIGNIFICANT		NO	NO	NO
CONDUCTIVITY (umhos/cm)	# OF READINGS	8	1	1	1
	MEAN	43781.25	42,000	35,500	43,000
	S	7615.1136	—	—	—
	t_*		-0.6616	-3.0758	-0.2902
	t_{comp}		1.895	1.895	1.895
	SIGNIFICANT		NO	NO	NO
TOC (1) (mg/l)	# OF READINGS	6	1	1	1
	MEAN	21.0313	<20	<20	<20
	S s^2	2.9168 8.5078	—	—	—
	t_*		-0.9697	-0.9697	-0.9697
	t_{comp}		2.015	2.015	2.015
	SIGNIFICANT		NO	NO	NO
TOX (mg/l)	# OF READINGS	8	1	1	1
	MEAN	0.2591	0.1975	0.1225	0.205
	S	0.3493	—	—	—
	t_*		-1.0321	-2.2895	-0.9064
	t_{comp}		1.895	1.895	1.895
	SIGNIFICANT		NO	NO	NO

(1) LIMITED DATA BOTH BACKGROUND AND DOWNGRADIENT WELLS.

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JOB HOVIC Statistics
SHEET NO. ____ OF ____
CALCULATED BY MRC DATE 12/2/85
CHECKED BY ____ DATE ____
SCALE ____

Mann-Whitney Test for pH

Landfarm	Well	n_2 or n_1 (n_2 = upgradient, n_1 = downgradient)	Value	U		P
II	2	D - n_1	7.03			
	1	U - n_2	7.2025	1	2	
	1	U - n_2	7.285	1	2	
	1	U - n_2	7.2875	1	2	
	3	D - n_1	7.3375			
	4	D - n_1	7.37			
	1	U - n_2	7.405	3	0	
	1	U - n_2	7.4525	3	0	
	1	U - n_2	7.5025	3	0	
	1	U - n_2	7.5325	3	0	
	1	U - n_2	7.575	3	0	
				18	6	0.139 @ u=6
				not significant		
III	1	U	6.8725	0	3	
	1	U	6.9775	0	3	
	1	U	7.0775	0	3	
	1	U	7.125	0	3	
	4	D	7.1275			
	2	D	7.2			
	3	D	7.3375			
	1	U	7.34	3	0	
	1	U	7.3625	3	0	
	1	U	7.4325	3	0	
	1	U	7.7925	3	0	
				12	12	0.539 @ u=12
				not significant		

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JOB Hovic Statistics

SHEET NO. ______ OF ______

CALCULATED BY MRC DATE 12/2/85

CHECKED BY ______ DATE ______

SCALE ______

Mann Whitney Test for Conductivity

Land farm	Ranked Value	Well #	Well Location	U	P
II	19,250	1	U	0	
	21,500	1	U	0	
	21,750	1	U	0	
	23,250	1	U	0	
	25,750	1	U	0	
	29,500	1	U	0	
	29,750	1	U	0	
	30,000	1	U	0	
	42,500	3	D		
	43,250	2	D		
	47,250	4	D		
				0	0.006

∴ conductivity significantly diffe @ 0.01 and 0.05 level

Land farm	Ranked Value	Well #	Well Location	U
III	26,000	1	U	0
	35,500	3	D	
	42,000	2	D	
	43,000	4	D	
	44,000	1	U	3
	44,500	1	U	3
	44,750	1	U	3
	45,000	1	U	3
	45,500	1	U	3
	50,000	1	U	3
	50,500	1	U	3
				21

not significant

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JOB Hovic Statistics
SHEET NO. ______ OF ______
CALCULATED BY MRC DATE 12/2/85
CHECKED BY ______ DATE ______
SCALE ______

Mann-Whitney Test for TOC

Landfarm	Value	Well #	Well Location	U	P
II	<10	4	D		
	<10	1	U	1	
	11.25	1	U	1	
	14.5	3	D		
	<20	1	U	2	
	<20	1	U	2	
	<20	1	U	2	
	<20	1	U	2	
	<20	1	U	2	
	26.5	1	U	2	
	51.5	2	D		
				14	
				not significant	
III	<10	1	U	0	
	<10	2	D		
	<10	3	D		
	<10	4	D		
	<10	1	U	3	
	<10	1	U	3	
	<20	1	U	3	
	<20	1	U	3	
	<20	1	U	3	
	<20	1	U	3	
	23.25	1	U	3	
				21	
				not significant	

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JOB: HOVIC Statistics
SHEET NO.
OF
CALCULATED BY: MRC
DATE: 12/2/85
CHECKED BY:
DATE:
SCALE:

Mann Whitney Test for TOX

Landfarm	Value	Well #	Well Location	U	P
II	0.0775	1	U	0	
	0.19	1	U	0	
	0.2675	1	U	0	
	0.285	3	D		
	0.305	1	U	1	
	0.315	2	D		
	0.33	4	D		
	0.35	1	U	3	
	0.435	1	U	3	
	0.435	1	U	3	
	2.720	1	U	3	
				13	
				not significant	
III	0.1225	3	D		
	0.18	1	U	1	
	0.19	1	U	1	
	0.1975	2	D		
	0.205	4	D		
	0.22	1	U	3	
	0.29	1	U	3	
	0.2925	1	U	3	
	0.6425	1	U	3	
	0.842	1	U	3	
	1.1	1	U	3	
				20	
				not significant	

TABLE 1. MODIFIED STUDENTS' t TEST FOR pH AT LANDFARMS II AND III

LANDFARM	MONITORING WELL #	MONITORING WELL # LOCATION	SAMPLING DATE	pH (s.u.)
II	NSF-1	upgradient	30-Nov-83	7.2850
	NSF-1	upgradient	06-Mar-84	7.2875
	NSF-1	upgradient	12-Apr-84	7.5750
	NSF-1	upgradient	03-Jun-84	7.4050
	NSF-1	upgradient	20-Aug-84	7.4525
	NSF-1	upgradient	28-Nov-84	7.5325
	NSF-1	upgradient	20-Mar-85	7.2025
	NSF-1	upgradient	01-Jul-85	7.5025
	NSF-2	downgradient	01-Jul-85	7.0300
	NSF-3	downgradient	01-Jul-85	7.3375
	NSF-4	downgradient	01-Jul-85	7.3700
III	SSF-1	upgradient	02-Jun-83	7.3750
	SSF-1	upgradient	27-Sep-83	7.1500
	SSF-1	upgradient	06-Mar-84	7.1250
	SSF-1	upgradient	03-Jun-84	7.3625
	SSF-1	upgradient	20-Aug-84	6.9775
	SSF-1	upgradient	28-Nov-84	7.4325
	SSF-1	upgradient	20-Mar-85	6.8725
	SSF-1	upgradient	01-Jul-85	7.0775
	SSF-2	downgradient	01-Jul-85	7.2000
	SSF-3	downgradient	01-Jul-85	7.3375
	SSF-4	downgradient	01-Jul-85	7.1275

NOTE: A - THERE HAS NOT BEEN A SIGNIFICANT CHANGE IN THIS PARAMETER

B - MOST LIKELY THERE HAS BEEN A SIGNIFICANT INCREASE (OR pH DECREASE)

pH IS A LOG FUNCTION

.)	$\overline{x}$-bg	s^2-bg	$\sqrt{s^2\text{-bg}/n}$	$\overline{x}$-dg	t*	tc	STANDING
7.2850							
7.2875							
7.5750							
7.4050							
7.4525							
7.5325							
7.2025							
7.5025							
	7.4053	0.0180	0.0475				
7.0300				7.0300	-7.9082	2.3650	B
7.3375				7.3375	-1.4289	2.3650	A
7.3700				7.3700	-0.7441	2.3650	A
7.3750							
7.1500							
7.1250							
7.3625							
6.9775							
7.4325							
6.8725							
7.0775							
	7.1716	0.0406	0.0713				
7.2000				7.2000	0.3990	2.3650	A
7.3375				7.3375	2.3280	2.3650	A
7.1275				7.1275	-0.6182	2.3650	A

IS PARAMETER

TABLE 2. MANN-WHITNEY U TEST FOR pH AT LANDFARMS II AND III

LANDFARM	MONITORING WELL #	MONITORING WELL # LOCATION	SAMPLING DATE	pH (s.u.)
II	NSF-2	downgradient	01-Jul-85	7.0300
	NSF-1	upgradient	20-Mar-85	7.2025
	NSF-1	upgradient	30-Nov-83	7.2850
	NSF-1	upgradient	06-Mar-84	7.2875
	NSF-3	downgradient	01-Jul-85	7.3375
	NSF-4	downgradient	01-Jul-85	7.3700
	NSF-1	upgradient	03-Jun-84	7.4050
	NSF-1	upgradient	20-Aug-84	7.4525
	NSF-1	upgradient	01-Jul-85	7.5025
	NSF-1	upgradient	28-Nov-84	7.5325
	NSF-1	upgradient	12-Apr-84	7.5750
III	SSF-1	upgradient	20-Mar-85	6.8725
	SSF-1	upgradient	20-Aug-84	6.9775
	SSF-1	upgradient	01-Jul-85	7.0775
	SSF-1	upgradient	06-Mar-84	7.1250
	SSF-4	downgradient	01-Jul-85	7.1275
	SSF-1	upgradient	27-Sep-83	7.1500
	SSF-2	downgradient	01-Jul-85	7.2000
	SSF-3	downgradient	01-Jul-85	7.3375
	SSF-1	upgradient	03-Jun-84	7.3625
	SSF-1	upgradient	02-Jun-83	7.3750
	SSF-1	upgradient	28-Nov-84	7.4325

NOTE: A - THERE HAS NOT BEEN A SIGNIFICANT CHANGE IN THIS PARAMETER

B - MOST LIKELY THERE HAS BEEN A SIGNIFICANT INCREASE (OR pH DECREASE)

pH IS A LOG FINCTION

P - PROBABILITY FROM TABLE 7, n2 = 8 IN ATTACHMENT 1

CONFIDENCE INTERVAL DOES NOT MEET POWER FOR 0.01 SIGNIFICANCE LEVEL
FOR pH -- MINIMUM P = 0.012

)	U-1	U-2 (pH only)	P-1	P-2 (pH only)	STANDING	CONFIDENCE INTERVAL
'.0300						
'.2025	1	2				
'.2850	1	2				
'.2875	1	2				
'.3375						
'.3700						
'.4050	3	0				
'.4525	3	0				
'.5025	3	0				
'.5325	3	0				
'.5750	3	0				
	18		).539		A	0.05
		6		0.278	A	0.05
;.8725	0	3				
;.9775	0	3				
'.0775	0	3				
'.1250	0	3				
'.1275						
'.1500	1	2				
'.2000						
'.3375						
'.3625	3	0				
'.3750	3	0				
'.4325	3	0				
	10		0.774		A	0.05
		14		).539	A	0.05

IS PARAMETER

TABLE 3. MODIFIED STUDENTS' t TEST FOR CONDUCTIVITY AT LANDFARMS II AND III

LANDFARM	MONITORING WELL #	MONITORING WELL # LOCATION	SAMPLING DATE	CONDUCTIVITY (umhos/cm)	C
II	NSF-1	upgradient	27-Sep-83	19,250	
	NSF-1	upgradient	06-Mar-84	30,000	
	NSF-1	upgradient	12-Apr-84	29,500	
	NSF-1	upgradient	03-Jun-84	29,750	
	NSF-1	upgradient	20-Aug-84	25,750	
	NSF-1	upgradient	28-Nov-84	21,750	
	NSF-1	upgradient	20-Mar-85	21,500	
	NSF-1	upgradient	01-Jul-85	23,250	
	NSF-2	downgradient	01-Jul-85	43,250	
	NSF-3	downgradient	01-Jul-85	42,500	
	NSF-4	downgradient	01-Jul-85	49,250	
III	SSF-1	upgradient	27-Sep-83	26,000	
	SSF-1	upgradient	06-Mar-84	44,500	
	SSF-1	upgradient	12-Apr-84	44,000	
	SSF-1	upgradient	03-Jun-84	50,500	
	SSF-1	upgradient	20-Aug-84	50,000	
	SSF-1	upgradient	28-Nov-84	44,750	
	SSF-1	upgradient	20-Mar-85	45,000	
	SSF-1	upgradient	01-Jul-85	45,500	
	SSF-2	downgradient	01-Jul-85	42,000	
	SSF-3	downgradient	01-Jul-85	35,500	
	SSF-4	downgradient	01-Jul-85	43,000	

NOTE: A - THERE HAS NOT BEEN A SIGNIFICANT CHANGE IN THIS PARAMETER

B - MOST LIKELY THERE HAS BEEN A SIGNIFICANT INCREASE (OR pH DECREASE)

IVITY	$\overline{x}$-bg	s^2-bg	$\sqrt{s^2\text{-bg}/n}$	$\overline{x}$-dg	t*	tc	STANDING
9.8653							
0.3090							
0.2921							
0.3006							
0.1562							
9.9874							
9.9758							
0.0541							
	10.1175	0.0295	0.0608				
0.6748				10.6748	9.1686	1.8950	B
0.6573				10.6573	8.8808	1.8950	B
0.8047				10.8047	11.3063	1.8950	B
0.1659							
0.7032							
0.6919							
0.8297							
0.8198							
0.7088							
0.7144							
0.7255							
	10.6699	0.0443	0.0744				
0.6454				10.6454	-0.3290	1.8950	A
0.4773				10.4773	-2.5878	1.8950	A
0.6690				10.6690	-0.0128	1.8950	A

IS PARAMETER

TABLE 4. MANN-WHITNEY U TEST FOR CONDUCTIVITY AT LANDFARMS II AND III

LANDFARM	MONITORING WELL #	MONITORING WELL # LOCATION	SAMPLING DATE	CONDUCTIVITY (umhos/cm)
II	NSF-1	upgradient	27-Sep-84	19,250
	NSF-1	upgradient	20-Mar-85	21,500
	NSF-1	upgradient	28-Nov-84	21,750
	NSF-1	upgradient	01-Jul-85	23,250
	NSF-1	upgradient	20-Aug-84	25,750
	NSF-1	upgradient	12-Apr-84	29,500
	NSF-1	upgradient	03-Jun-84	29,750
	NSF-1	upgradient	06-Mar-84	30,000
	NSF-3	downgradient	01-Jul-85	42,500
	NSF-2	downgradient	01-Jul-85	43,250
	NSF-4	downgradient	01-Jul-85	49,250
III	SSF-1	upgradient	27-Sep-84	26,000
	SSF-3	downgradient	01-Jul-85	35,500
	SSF-2	downgradient	01-Jul-85	42,000
	SSF-4	downgradient	01-Jul-85	43,000
	SSF-1	upgradient	12-Apr-84	44,000
	SSF-1	upgradient	06-Mar-84	44,500
	SSF-1	upgradient	28-Nov-84	44,750
	SSF-1	upgradient	20-Mar-85	45,000
	SSF-1	upgradient	01-Jul-85	45,500
	SSF-1	upgradient	20-Aug-84	50,000
	SSF-1	upgradient	03-Jun-84	50,500

NOTE: A - THERE HAS NOT BEEN A SIGNIFICANT CHANGE IN THIS PARAMETER

B - MOST LIKELY THERE HAS BEEN A SIGNIFICANT INCREASE) IN THIS PARAME

SEE ATTACHMENT 1, TABLE J FOR N2 FOR PROBABILITIES (P-1 OR P-2) VERSU

n TIVITY	U-1	U-2 (pH only)	P-1	P-2 (pH only)	STANDING	CONFIDENCE INTERVAL
9.8653	0					
9.9758	0					
9.9874	0					
10.0541	0					
10.1562	0					
10.2921	0					
10.3006	0					
10.3090	0					
10.6573						
10.6748						
10.8047						
	0		0.006		B	0.05
					B	0.01
10.1659	0					
10.4773						
10.6454						
10.6690						
10.6919	3					
10.7032	3					
10.7088	3					
10.7144	3					
10.7255	3					
10.8198	3					
10.8297	3					
	12		0.539		A	0.05
					A	0.01

TABLE 5. MODIFIED STUDENTS' t TEST FOR TOC AT LANDFARMS II AND III

LANDFARM	MONITORING WELL #	MONITORING WELL # LOCATION	SAMPLING DATE	TOC (mg/l)
II	NSF-1	upgradient	02-Jun-83	20.0000
	NSF-1	upgradient	27-Sep-83	20.0000
	NSF-1	upgradient	06-Mar-84	20.0000
	NSF-1	upgradient	03-Jun-84	20.0000
	NSF-1	upgradient	20-Aug-84	20.0000
	NSF-1	upgradient	28-Nov-84	10.0000
	NSF-1	upgradient	20-Mar-85	26.5000
	NSF-1	upgradient	01-Jul-85	11.2500
	NSF-2	downgradient	01-Jul-85	51.5000
	NSF-3	downgradient	01-Jul-85	14.5000
	NSF-4	downgradient	01-Jul-85	10.0000
III	SSF-1	upgradient	02-Jun-83	20.0000
	SSF-1	upgradient	27-Sep-83	20.0000
	SSF-1	upgradient	06-Mar-84	20.0000
	SSF-1	upgradient	03-Jun-84	28.2500
	SSF-1	upgradient	20-Aug-84	20.0000
	SSF-1	upgradient	28-Nov-84	10.0000
	SSF-1	upgradient	20-Mar-85	10.0000
	SSF-1	upgradient	01-Jul-85	10.0000
	SSF-2	downgradient	01-Jul-85	10.0000
	SSF-3	downgradient	01-Jul-85	10.0000
	SSF-4	downgradient	01-Jul-85	10.0000

NOTE: A - THERE HAS NOT BEEN A SIGNIFICANT CHANGE IN THIS PARAMETER

B - MOST LIKELY THERE HAS BEEN A SIGNIFICANT INCREASE (OR pH DECREASE)

:	$\overline{x}$-bg	s-bg^2	$\sqrt{\text{s-bg}^2/n}$	$\overline{x}$-dg	t*	tc	STANDING
2.9957							
2.9957							
2.9957							
2.9957							
2.9957							
2.3026							
3.2771							
2.4204							
	2.8723	0.1098	0.1172				
3.9416				3.9416	9.1250	1.8950	B
2.6741				2.6741	-1.6914	1.8950	A
2.3026				2.3026	-4.8624	1.8950	A
2.9957							
2.9957							
2.9957							
3.3411							
2.9957							
2.3026							
2.3026							
2.3026							
	2.7790	0.1693	0.1455				
2.3026				2.3026	-3.2752	1.8950	A
2.3026				2.3026	-3.2752	1.8950	A
2.3026				2.3026	-3.2752	1.8950	A

S PARAMETER

TABLE 6. MANN-WHITNEY U TEST FOR TOC AT LANDFARMS II AND III

LANDFARM	MONITORING WELL #	MONITORING WELL # LOCATION	SAMPLING DATE	TOC (mg/l)
II	NSF-4	downgradient	01-Jul-85	10.0000
	NSF-1	upgradient	28-Nov-84	10.0000
	NSF-1	upgradient	01-Jul-85	11.2500
	NSF-3	downgradient	01-Jul-85	14.5000
	NSF-1	upgradient	02-Jun-83	20.0000
	NSF-1	upgradient	06-Mar-84	20.0000
	NSF-1	upgradient	03-Jun-84	20.0000
	NSF-1	upgradient	20-Aug-84	20.0000
	NSF-1	upgradient	27-Sep-83	20.0000
	NSF-1	upgradient	20-Mar-85	26.5000
	NSF-2	downgradient	01-Jul-85	51.5000
III	SSF-1	upgradient	20-Mar-85	10.0000
	SSF-3	downgradient	01-Jul-85	10.0000
	SSF-2	downgradient	01-Jul-85	10.0000
	SSF-1	upgradient	28-Nov-84	10.0000
	SSF-4	downgradient	01-Jul-85	10.0000
	SSF-1	upgradient	01-Jul-85	10.0000
	SSF-1	upgradient	06-Mar-84	20.0000
	SSF-1	upgradient	27-Sep-83	20.0000
	SSF-1	upgradient	20-Aug-84	20.0000
	SSF-1	upgradient	02-Jun-83	20.0000
	SSF-1	upgradient	03-Jun-84	28.2500

NOTE: A - THERE HAS NOT BEEN A SIGNIFICANT CHANGE IN THIS PARAMETER

B - MOST LIKELY THERE HAS BEEN A SIGNIFICANT INCREASE (OR pH DECREASE)

P - PROBABILITY FROM TABLE 7, n2 = 8 IN ATTACHMENT 1

)C	U-1	U-2 (pH only)	P-1	P-2 (pH only)	STANDING	CONFIDENCE INTERVAL
2.3026						
2.3026	1					
2.4204	1					
2.6741						
2.9957	2					
2.9957	2					
2.9957	2					
2.9957	2					
2.9957	2					
3.2771	2					
3.9416						
	14		).539		A	0.05
					A	0.01
2.3026	0					
2.3026						
2.3026						
2.3026	2					
2.3026						
2.3026	3					
2.9957	3					
2.9957	3					
2.9957	3					
2.9957	3					
3.3411	3					
	20		).539		A	0.05
					A	0.01

IIS PARAMETER

TABLE 7. MODIFIED STUDENTS' t TEST FOR TOX AT LANDFARMS II AND III

LANDFARM	MONITORING WELL #	MONITORING WELL # LOCATION	SAMPLING DATE	TOX (mg/l)
II	NSF-1	upgradient	02-Jun-83	0.3500
	NSF-1	upgradient	27-Sep-83	0.2675
	NSF-1	upgradient	06-Mar-84	0.1900
	NSF-1	upgradient	03-Jun-84	0.4350
	NSF-1	upgradient	20-Aug-84	0.4350
	NSF-1	upgradient	28-Nov-84	0.3050
	NSF-1	upgradient	20-Mar-85	0.0500
	NSF-1	upgradient	01-Jul-85	0.0775
	NSF-2	downgradient	01-Jul-85	0.3150
	NSF-3	downgradient	01-Jul-85	0.2850
	NSF-4	downgradient	01-Jul-85	0.3300
III	SSF-1	upgradient	27-Sep-83	0.6425
	SSF-1	upgradient	06-Mar-84	0.2750
	SSF-1	upgradient	12-Apr-84	0.1800
	SSF-1	upgradient	03-Jun-84	0.1900
	SSF-1	upgradient	20-Aug-84	0.2000
	SSF-1	upgradient	28-Nov-84	0.2925
	SSF-1	upgradient	20-Mar-85	0.0725
	SSF-1	upgradient	01-Jul-85	0.2200
	SSF-2	downgradient	01-Jul-85	0.1975
	SSF-3	downgradient	01-Jul-85	0.1225
	SSF-4	downgradient	01-Jul-85	0.2050

NOTE: A - THERE HAS NOT BEEN A SIGNIFICANT CHANGE IN THIS PARAMETER

B - MOST LIKELY THERE HAS BEEN A SIGNIFICANT INCREASE (OR pH DECREASE)

n DX	$\overline{x}$-bg	s^2-bg	$\sqrt{s^2\text{-bg}/n}$	$\overline{x}$-dg	t*	tc	STANDING
-1.0498							
-1.3186							
-1.6607							
-0.8324							
-0.8324							
-1.1874							
-2.9957							
-2.5575							
	-1.5543	0.6546	0.2861				
-1.1552				-1.1552	1.3954	1.8950	A
-1.2553				-1.2553	1.0455	1.8950	A
-1.1087				-1.1087	1.5580	1.8950	A
-0.4424							
-1.2910							
-1.7148							
-1.6607							
-1.6094							
-1.2293							
-2.6242							
-1.5141							
	-1.5107	0.3689	0.2147				
-1.6220				-1.6220	-0.5182	1.8950	A
-2.0996				-2.0996	-2.7423	1.8950	A
-1.5847				-1.5847	-0.3446	1.8950	A

IIS PARAMETER

TABLE 8. MANN-WHITNEY U TEST FOR TOX AT LANDFARMS II AND III

LANDFARM	MONITORING WELL #	MONITORING WELL # LOCATION	SAMPLING DATE	TOX (mg/l)
II	NSF-1	upgradient	20-Mar-85	0.0500
	NSF-1	upgradient	01-Jul-85	0.0775
	NSF-1	upgradient	06-Mar-84	0.1900
	NSF-1	upgradient	27-Sep-83	0.2675
	NSF-3	downgradient	01-Jul-85	0.2850
	NSF-1	upgradient	28-Nov-84	0.3050
	NSF-2	downgradient	01-Jul-85	0.3150
	NSF-4	downgradient	01-Jul-85	0.3300
	NSF-1	upgradient	02-Jun-83	0.3500
	NSF-1	upgradient	20-Aug-84	0.4350
	NSF-1	upgradient	03-Jun-84	0.4350
III	SSF-1	upgradient	20-Mar-85	0.0725
	SSF-3	downgradient	01-Jul-85	0.1225
	SSF-1	upgradient	06-Mar-84	0.1800
	SSF-1	upgradient	03-Jun-84	0.1900
	SSF-2	downgradient	01-Jul-85	0.1975
	SSF-1	upgradient	20-Aug-84	0.2000
	SSF-4	downgradient	01-Jul-85	0.2050
	SSF-1	upgradient	01-Jul-85	0.2200
	SSF-1	upgradient	27-Sep-83	0.2750
	SSF-1	upgradient	28-Nov-84	0.2925
	SSF-1	upgradient	02-Jun-83	0.6425

NOTE: A - THERE HAS NOT BEEN A SIGNIFICANT CHANGE IN THIS PARAMETER

B - MOST LIKELY THERE HAS BEEN A SIGNIFICANT INCREASE (OR pH DECREASE

P - PROBABILITY FROM TABLE 7, n2 = 8 IN ATTACHMENT 1

1 DX	U-1	U-2 (pH only)	P-1	P-2 (pH only)	STANDING	CONFIDENCE INTERVAL
-2.9957	0					
-2.5575	0					
-1.6607	0					
-1.3186	0					
-1.2553						
-1.1874	1					
-1.1552						
-1.1087						
-1.0498	3					
-0.8324	3					
-0.8324	3					
	10		0.387		A	0.05
					A	0.01
-2.6242	0					
-2.0996						
1.7148	1					
-1.6607	1					
1.6220						
-1.6094	2					
1.5847						
-1.5141	3					
1.2910	3					
1.2293	3					
0.4424	3					
	16		>0.539		A	0.05
					A	0.01

IS PARAMETER

ATTACHMENT 4

GROUNDWATER QUALITY DATA
IN-SITU VERSUS LABORATORY

TABLE 2. GROUNDWATER QUALITY PARAMETERS MEASURED AT LANDFARM III DURING SKINNER LIST

DATE	TIME	WELL #	ELEV (ft NGVD)	DEPTH (ft below GW surf)	IN SITU WATER T (°C)	LAB WATER T (°C)
29-Oct-85	1230	SSF1	14.21	1.0	28.8	
				3.0	28.6	
				6.0	28.5	
				9.0	28.4	
				12.0	28.3	
30-Oct-85	1623	SSF1		1.0	28.6	
30-Oct-85	1903	SSF1				22.0
						22.0
						22.0
						22.0
29-Oct-85	1030	SSF2	11.09	2.5	28.7	
				5.5	not read	
30-Oct-85	1415	SSF2		1.0	28.6	
30-Oct-85	1903	SSF2				22.0
						22.0
						22.0
						22.0
29-Oct-85	1100	SSF3	2.07	1.0	28.1	
				1.5	28.1	
				3.0	28.1	
				5.0	28.1	
30-Oct-85	1449	SSF3		1.0	28.2	
30-Oct-85	1903	SSF3				22.5
						22.5
						22.5
						22.5
29-Oct-85	1145	SSF4		1.0	28.5	
				3.0	28.4	
				6.0	28.3	
30-Oct-85	1518	SSF4		1.0	28.5	
30-Oct-85	1903	SSF4				22.5
						22.5
						22.5
						22.5

NOTE : BOTH SULFIDES AND FERROUS IRON CAUSE INTERFERENCES IN DO MEASUREMENTS IN GROUN
DO MEASUREMENTS WERE MADE WITH A YSI PROBE

FIELD MEASUREMENTS MADE USING A HYDOLAB SYSTEM 8000 WATER QUALITY INSTRUMENT

ING

TU I 1)	IN SITU pH (s.u.)	LAB pH (s.u.)	IN SITU COND (umhos/cm)	LAB COND (umhos/cm)	IN SITU ORP (mv)	COMMENTS
2.8	6.55		>20,000		159	BEFORE PUMPING
1.5	6.80		>20,000		50	
1.2	6.85		>20,000		21	
1.0	6.85		>20,000		10	
2.0	6.85		>20,000		4	
1.2	6.00				252	AFTER PUMPING
		7.30		38,000		
		7.05		37,500		
		7.15		38,000		
		7.05		37,000		
1.9	6.30		>20,000		213	BEFORE PUMPING
ead	not read		not read		not read	
1.7	5.70				511	AFTER PUMPING
		7.20		35,000		
		7.00		37,500		
		7.05		33,500		
		7.00		33,500		
2.3	6.50		>20,000		111	BEFORE PUMPING
1.8	6.60		>20,000		95	
1.2	6.70		>20,000		72	
1.4	6.70		>20,000		55	
1.0	5.80				390	AFTER PUMPING
		7.45		29,000		
		7.15		30,000		
		7.05		39,000		
		7.15		30,000		
2.3	6.70		>20,000		-10	BEFORE PUMPING
1.4	6.75		>20,000		-23	
1.0	6.77		>20,000		-29	
1.1	6.10				222	AFTER PUMPING
		7.20		38,000		
		6.90		39,000		
		6.85		37,000		
		6.90		37,000		

RS USING A PROBE

TABLE 1. GROUNDWATER QUALITY PARAMETERS MEASURED AT LANDFARM II DURING SKINNER LIST !

DATE	TIME	WELL #	ELEV (ft NGVD)	~DEPTH (ft below GW surf)	IN SITU WATER T (°C)	LAB WATER T (°C)
29-Oct-85	1630	NSF1	20.35	1.0	28.4	
				3.0	28.4	
				6.0	28.4	
30-Oct-85	1722	NSF1		1.0	28.6	
30-Oct-85	1903	NSF1				22.5
						22.5
						22.5
						22.5
30-Oct-85	1125	NSF2	19.62	1.0	29.5	
				3.0	29.5	
				6.0	29.4	
31-Oct-85	1041	NSF2		1.0	29.6	
	1530	NSF2				
30-Oct-85	1100	NSF3	17.69	1.0	29.1	
				3.0	29.2	
				6.0	29.2	
31-Oct-85	1014	NSF3		1.0	29.1	
		NSF3				
30-Oct-85	1530	NSF4	13.49	1.0	28.1	
				3.0	28.1	
				6.0	28.1	
30-Oct-85	1656	NSF4		1.0	28.0	
30-Oct-85	1903	NSF4				22.5
						22.5
						22.5
						22.5

NOTE : BOTH SULFIDES AND FERROUS IRON CAUSE INTERFERENCES IN DO MEASUREMENTS IN GROU
DO MEASUREMENTS WERE MADE WITH A YSI PROBE

FIELD MEASUREMENTS MADE USING A HYDOLAB SYSTEM 8000 WATER QUALITY INSTRUMENT

NG

TU) 1)	IN SITU pH (s.u.)	LAB pH (s.u.)	IN SITU COND (umhos/cm)	LAB COND (umhos/cm)	IN SITU ORP (mv)	COMMENTS
2.5	6.40		>20,000		522	BEFORE PUMPING
1.0	6.10		>20,000		336	
0.9	6.20		>20,000		306	
0.9	6.55		>20,000		170	AFTER PUMPING
		7.40		21,000		
		7.15		20,000		
		7.10		20,000		
		7.15		20,000		
1.7	6.00		>20,000		254	BEFORE PUMPING
0.8	6.20		>20,000		202	
0.6	6.20		>20,000		183	
1.3	6.10				410	AFTER PUMPING
		6.75		32,000		
		6.85		33,000		
		6.90		32,000		
		6.70		32,000		
ead	6.00		>20,000		274	BEFORE PUMPING
ead	6.20		>20,000		255	
0.9	6.30		>20,000		238	
1.3	6.10				372	AFTER PUMPING
		6.95		32,000		
		7.00		33,500		
		7.05		32,000		
		6.85		33,000		
1.8	6.50		>20,000		-20	BEFORE PUMPING
1.2	6.60		>20,000		-27	
0.9	6.70		>20,000		-26	
1.3	6.05				140	AFTER PUMPING
		7.25		38,000		
		7.00		39,000		
		6.95		39,000		
		6.95		39,500		

ERS USING A PROBE